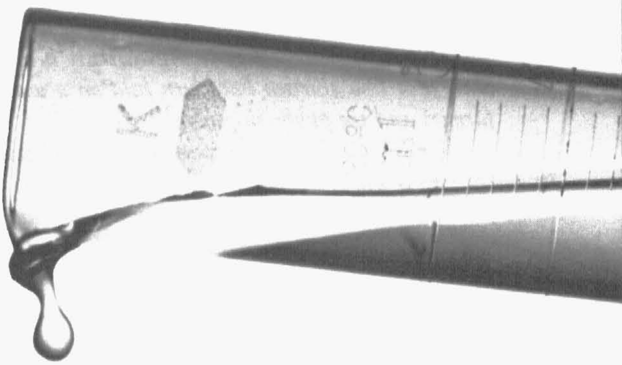
WATER FORUM



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University of Missouri
College of Agriculture
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Foreword

The Missouri College of Agriculture held its first public policy Forum in 1949. Since that time thirteen have been held on a wide range of public problems which affect farmers and the public in general.

The purpose of these Forums is to provide those in attendance with information about the subject under discussion. Those attending are not expected to pass resolutions or support a particular view but do have an opportunity to ask questions or make comments.

The 1965 Forum, held during Agricultural Science Week, was concerned with the broad area of water resource development and use. The subjects discussed by leading authorities in the field included the role of water in economic development, economics of competition for its use, legal aspects of water use and current water quality problems associated with sewage and industrial wastes, pesticides and nitrates. An earlier Forum on water was held in 1956.

The talks, expressing the views of the speakers, were given at the 1965 Water Forum and are presented here for the information of interested persons.

Talks Presented at 13th Public Policy Forum

Emerging Water Problems in Missouri

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The water problems of Missouri encompass both surface and ground water. It is recognized we can no longer think of surface and ground water as separate entities; the separation of the two herein is only for convenience of discussion.

Ground Water

Although Missouri has a large amount of ground water data there are still some major questions which must be answered for full future development of ground water resources. We do not know the yield of our individual major aquifers (water bearing strata) with any exactitude, especially those developed in bedrock. Rather, we know the typical yields of individual wells, each of which penetrates several aquifers, and thus when we state "A Potosi well in X County will yield 400 gallons per minute" we are actually saying that a well which *penetrates* the Potosi formation in X County yields so many gallons per minute. This well may produce from several higher formations and the information we give is not a yield figure for the Potosi alone. Because of this problem of composite yields we cannot give accurate estimates for the potential yield of any given bedrock aquifer. To give such answers we need a carefully controlled pumping test with proper casing to determine the yield of each individual aquifer of the several which may be represented in a given well.

Another problem of quantity is the question of whether we are mining water of the geologic past or whether the water we use is being replaced through the normal contemporary hydrologic cycle. The answer to this question could be obtained through very careful maintenance of observation wells, detailed pumping tests, appropriate radioactive or chemical tracers, and radioactive dating which would give us the absoulte age of water we are using today.

Northern Missouri has been an area of water problems for many years because the ground water in bedrock is highly mineralized and wells which produce large quantities of water generally are those in glacial drift. Although a test drilling program has outlined the location of deep valleys cut in bedrock and filled with glacial drift in the northwestern counties, this program is not complete and the accurate location of such valleys in northeastern Missouri is an unknown. Test drilling and geophysical methods of mapping such valleys are a necessity for the future water development of northeastern Missouri.

A completely new source of water will undoubtedly be developed in the future when current research on the demineralization of water makes such techniques economically feasible. When demineralization is feasible, the problem of adequate water which has inhibited industrial growth in the northern part of the state will be at least partly solved. The question of mineralized aquifer yield will need much work because we have hardly any such data at present. If funds and personnel were available we should today be carrying on deep drilling and pumping tests in these mineralized aquifers which will probably be major sources of tomorrow's water. The demineralization of water for industry and municipalities will undoubtedly result in a demand for very small scale demineralization units to take care of the domestic water user. As the demand for domestic water increases with the new uses in air conditioning, automatic washers, dishwashers and other equipment, the small well or cistern which has been sufficient for the rural home-owner in northern Missouri will no longer be sufficient and the home-owner will need a relatively inexpensive method of demineralizing water. At the same time he will be undoubtedly subject to the pressure of the few unscrupulous water conditioner salesmen who attempt to convince him that their conventional equipment will purify highly mineralized water. From time to time such sales promotions have plagued us and they will undoubtedly become more frequent.

The status of ground water rights in Missouri is vague and the little precedent we have would indicate that one may use all of the ground water he wishes as long as he puts it to beneficial use and does not injure the adjacent property owner with malicious intent. As ground water use increases there will be increasing interference of neighboring wells and legislation will undoubtedly be needed to protect rights and resolve litigations.

There is so much concern over water quality that I do not want to dwell on many of the aspects of it. Yet I should mention some problems which have not received a great amount of attention. For example, there is from time to time an effort to promote the storage of radioactive wastes in mineralized aquifers with the attitude that the water is mineralized and thus is of no use. With the feasibility of ground water demineralization a certainty in the near future, the storage of radioactive wastes in such waters should be completely discouraged.

We also face an increasing problem in the encroachment of mineralized waters into fresh water aquifers, and strict control of well drilling, plugging, and casing is required to minimize such encroachment. It is quite possible that Missouri's oil production may increase greatly. If it does, we must have control of both salt water encroachment and waste disposal. Controls are also needed which would require the plugging of abandoned water wells to eliminate the use of such abandoned wells for waste disposal, a practice which is not at all uncommon. Sink holes are also used for waste and storm water disposal in many areas—a luxury which cannot be afforded.

Surface Water

The question of surface water rights is also a major one and I mention it only for the sake of completion with the realization that it will become increasingly important and that legislation will be needed. On a grand scale we will undoubtedly face increasing competition with upstream states on the Missouri and Mississippi Rivers and Missouri must have a strong voice in demanding its share of flow.

A problem which is now emerging in urban areas is that of increased run-off as major construction greatly reduces the exposure of bare ground and thus creates a greater possibility of flash flooding in these areas and in downstream environs. Will we need new retention facilities in urban areas as they become huge impervious rain collectors?

As privately-owned surface impoundments are constructed, in addition to being faced with increasing problems of water apportionment, we will be faced with the responsibility of protecting the safety of those living downstream. We already have one case of a relatively large private impoundment which was constructed without proper engineering advice which poses a potential hazard of structural failure. Construction of such dams will require much more careful engineering supervision in the future as they become more numerous, population becomes more dense, and as the size of impoundments grows.

When we consider the relationship of surface and ground water as an integrated unit we realize that we know very little about the recharging of our ground waters and that very little research has been carried on in recharge or water-flooding techniques. Such studies will be needed as water becomes a more precious commodity and we are forced to aid nature in replenishing ground water resources.

Some pollution problems such as pesticides, detergents, nitrates, and chemical waste are obvious in their results. Perhaps, as I am certain some of you realize, the dangers of pollution may not be obvious and may result in slow, subtle health hazards. Could the effects of nitrates on humans or animals be masquerading as diagnosed circulatory ailments such as hardening of the arteries, or heart trouble? Could detergents produce symptoms diagnosed as those normal to old age? Perhaps those of you in the field of veterinary medicine are ahead of your brethren practicing human medicine in such research.

Research and Administration

It is obvious that much research is needed in the field of ground water. Missouri has lagged behind in such research because of the lack of funds. The salary scale of state employees is so low that it is very difficult to obtain and hold qualified men not only because of the competition from industry but also because federal salaries and out-of-state governmental salaries are at a higher scale. Even if salaries were increased greatly we would still find it difficult to maintain research and control staffs because of the lack of trained personnel. The establishment of a Water Resources Center in the University of Missouri System offers the opportunity for research in major ground water problems but to me it is of equal or even greater importance in offering training in the broad field of water resources and in encouraging men to enter this unpublicized field in addition to the more obvious (water involved) fields of science, engineering, economics, health, and law.

If we were to have sufficient funds and sufficient men to carry on water research and administration we might face still another problem, that of administration. Because there is a considerable amount of interest in water, there is the possible danger of too many agencies working without coordination in such a popular field and the danger of overlapping of frenzied unhealthy competition. There are those who would state that we need one giant organization in the state to do all types of work connected with water. I feel such an organization is physically impossible but I do feel that an assignment of responsibilities and the assurance of cooperation and coordination between the various water agencies and research institutions which is now a reality might become less easily realized if there is a major expansion in water service, research, and control.

Undoubtedly we need legislation defining water rights, adding still more teeth to water pollution control, and requiring the compulsory saving of data from drilled wells. Unfortunately, the climate is still not one which favors such legislation. Additional regulatory and control legislation is frowned on as regimentation and there is sometimes the attitude that such legislation infringes on the rights of the individual. With our growing population and the growing dangers of pollution, conflicting water use, and the need for water resource data we must sacrifice some of our individualism and realize that legislation is needed to control the drilling of every water well in the state, to require the saving of data from such drilling, to require the proper casing of all water wells, and require the proper plugging of abandoned wells.

A phase of what might be considered water rights is involved in the proper spacing of wells. To date the spacing of large industrial and municipal wells has been fairly well controlled on a voluntary and advisory basis but it may be necessary to have legislation establishing the authority for compulsory spacing of wells. In closing, I might mention that we need funds badly for the control of wells used by the public. State agencies do excellent work with the money they have, but because of limited funds and personnel the definition of public must necessarily be a limited one and certain types of wells which supply water to a large number of people still are not considered as public for water control purposes; and I greatly fear that only a dramatic epidemic or pollution case will produce the needed funds to assure the safeguarding of all public wells.

In conclusion I would say that I am optimistic regarding our ability to solve the majority of the water problems cited but I am concerned that we may wait for solution through delayed reaction rather than through anticipation.

Missouri Water Law: Some Facts, Assumptions and Suggestions

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There is no legislative statement of policy regarding the use or development of the waters of Missouri.

Except for some special provisions in the law and except for local regulation of water use and movement by municipalities, drainage districts and other local entities, the water law of Missouri depends primarily on court decisions.

In dealing with water, the courts have developed different rules depending on source; the three important categories being: stream water, percolating ground water and surface water.

The following rules have been developed regarding stream water.

A. To constitute a water course and hence stream water there must be a definite channel in a particular direction though the stream need not flow continually. It must be something more than mere surface drainage occasioned by unusual rainstorms or other extraordinary causes. Water in hollows and ravines and sloughs which carry off flood water are not water courses.

B. The Riparian Doctrine applies in Missouri as opposed to the Prior Appropriation Doctrine which applies in most of the western states.

C. There are two major schools of thought within the Riparian Doctrine itself; one designated the natural flow theory which pretends to create an absolute right to the undisturbed flow of the water except for certain uses; the other a reasonable use theory which would allow for not only domestic use but certain expanded uses which Riparian owners might need to make. In Missouri the reasonable use application of the Riparian Doctrine seems to apply.

The following important problems arise out of any doctrine which has to do with the use of stream water.

A. How much water can any Riparian owner use and for what purpose?

B. What rights do municipalities have to use water from streams for municipal water supply? Are there any laws which give them special privileges?

C. What industrial use can be made of stream water?

D, What are the irrigation rights of Riparian owners?

E. What are the controls on pollution of stream water by either industry, municipality or individual?

F. In case of severe shortages, what uses get honored and who determines how they are honored and to what extent?

G. What is the legal position of an artificial water course? Apparently, artificial water courses may in time take on the characteristics of natural water courses. An interest in such artificial water courses may arise by grant, contract or prescription. There is a much greater possibility for proprietary rights in an artificial water course.

Missouri decisions on percolating ground water are not plentiful. Also, there are no statutes which have any important bearing on the right to use such water. The following will be assumed:

A. Any underground water which follows a natural course and can be identified geologically as a stream will be subject to the same rules as a stream on the surface of the earth which means that in Missouri it would be subject to the Riparian doctrine.

B. Water percolating through the soil but diffused and not in a channel of any kind is probably subject to the same ownership rights as the soil itself or minerals in the soil. This means that the owner can use as much of it as he likes at any time he likes regardless of any damage it might cause to adjoining landowners. This is sometimes referred to as the tooth and fang theory regarding percolating waters, but it seems to be the theory which holds in most of the United States. This raises serious question when a municipality, for example, by sinking deep wells on property which it might purchase or rent lowers the water table in the whole neighborhood. Under the doctrine which probably prevails, the injured adjoining owners have no recourse.

The drainage of surface waters in Missouri is subject to the so-called common enemy rule which is that such water is a common enemy and every man may ward it off his land and throw it on adjacent or lower owners' providing he does not unnecessarily collect it and discharge it to the damage of his neighbor. The amount and extent of collection and discharge must be reasonable in relation to the needs of the parties involved. Overflow waters from natural water courses are treated as surface drainage water, and the common enemy rule applies. A Missouri statute empowers an upper landowner to use eminent domain to secure the right to build drains across a neighbor's land for agricultural purposes where such is found to be necessary. Drainage districts, of course, have been the organized answer to the problem of getting a large area of relatively flat land drained in a legal and equitable fashion.

What are some things which would make for some improvement in Missoui water law and how may they be effectuated?

A. There has been a great interest in Missouri in many groups in getting the water laws of the state improved and in getting some kind of water use legislation which would insure a more economical and beneficial use of water. Interest in getting this kind of legislation should be fostered and cultivated. All groups which are affected should be brought together in an effort to study and approve the kind of legislation which would institute the sort of control necessary to get this beneficial and wise use of water but without impairing any more private rights than is necessary.

This raises an interesting question; namely, that of property rights in water. The Illinois Supreme Court has held that running water does not constitute a freehold apparently because the water doesn't remain long enough. Apparently the court was impressed with motion. After all, the particles of the soil which it would say undoubtedly constitute a part of the freehold do change in character and sometimes disappear through the slow process of erosion or absorption by plants. Some of the minerals from your soil are no doubt in the bellies of citizens of India via the wheat export program. This line of thought is too tempting. Perhaps I should desist.

B. Do your lows on pollution need strengthening? The common law theory against pollution of water is rather well developed and all states have statutes which to some degree prohibit the dumping of certain offensive substances, sometimes even including raw sewage, into the streams or water courses of the state.

C. Can your drainage laws be overhauled to advantage? We did this in Illinois a few years ago and feel that the result was well worthwhile. It streamlined many of the procedures and simplified the process under which drainage districts were formed.

D. A water use law with a method of determining priorities and a method of arriving at administrative determinations but with the right to appeal to the courts would be helpful. Currently, the courts are the tribunal in which water use rights are argued. The body of court opinion is now sufficient in size so that together with the legislative and regulatory provisions which do exist an administrative tribunal with some stature could be of great help.

What agencies would be involved in an improvement and revamping of Missouri's water laws?

The uses for water are diverse and there are many strong and articulate agencies within the state of Missouri whose viewpoints differ regarding the best use of water. Somehow these viewpoints must be rationalized if a sound water use policy is to be implemented and if it is to contain the sanctions necessary to make it effective. Not being familiar with Missouri agencies or with the past history of your efforts to get an improved system of water laws, I would simply hazard that the following agencies all have strong vested interests and would have to be pulled together if anything is to be done.

A. Your various state agencies with planning, water and drainage responsibilities.

B. Your municipalities, especially if they are represented by an organization such as a municipal league.

C. Your sports organizations, especially the Isaac Walton League, outdoor organizations and other sportsmans' groups.

D. Your manufacturer's associations.

E. Agricultural groups and associations.

F. The drainage interests.

G. Your well drillers and their organization.

H. The research agencies in your university or universities, particularly your agricultural, geologic and engineering branches.

I. Your soil conservation associations, both voluntary and governmental.

J. Conservancy districts and other public corporations which may be formed to deal with water.

K. Water authorities and other agencies which may be established to supply water to municipalities or for other purposes.

L. Your state sanitary water board or its equivalent which would have to do with the pollution of streams and waters of the state.

What kinds of entities are needed?

Attempts to qualify under the federal watershed program have focused attention on the need for agencies which can sponsor an over-all water development in local areas. In view of the fact that a large number of entities already exist, each with a rather specific purpose complicates the situation. There may be local agencies which have a broad enough scope to accomplish all the things comprehended under watershed development. The River Conservancy District, for example, might answer this purpose, but there is still the problem of jurisdiction and what happens to the rights and powers and responsibilities of agencies already in the proposed district which have particular functions? I refer especially to drainage districts and water authorities of various kinds.

This is not an easy problem. It can be attacked in one of two general ways: either by creating an agency which simply takes over all the functions and responsibilities of agencies in existence, in which case they either just die on the vine or perhaps continue with limited functions, or else the over-all agency can be primarily a coordinating body which simply brings together all the diverse groups that have to do with water, encouraging each of them to do all it can within the scope of its authority and in this way bringing out a rounded program for an area. We are wrestling with this one in Illinois and we have not found the answer. Should there be an over-all plan for studying the development of water resources in Missouri? Should a state agency undertake the task of inventorying the total water resources of the state and developing a master plan for their utilization and future use? How should the state be subdivided for purposes of water development and control? Is the river basin notion feasible in whole or in part? Are your present political subdivisions amenable to this use or are different entities implied?

What deterrents willl there be to improving your water laws? The following will probably all be important.

A. The fear of control and the possibility that the property concept of water might be destroyed.

B. The probability that any legislative proposal will be branded as partisan by some one or more of the many user interests.

C. The feeling by some that Missouri is generally well supplied with water and that problems will continue to be local in character and hence best solved by local control through some one or more of the public corporations which may be created by petition or referendum.

D. The difficulty of pulling together all the various interest groups so sound legislation can be drafted with a chance of adoption.

E. The difficulty in establishing the kind of central organization or water study group which can eventually lead to something effective.

"Water resource developments, comprising elements of private and public fiscal, economic, social, and political policy, are a fertile field for the generation of conflicts. For those interested in optimal solution of conflicts, the whole field is an area of maximum frustration. ...

"Many conflicts would not arise, or would be less severe, if the planning to which they were a reaction had been better. Thus, a first and major step for improvement is prevention by better planning, in which conflicts are anticipated and alternative solutions analyzed. This means increased professionalization and sophistication at all levels of planning, including review and coordinating levels. It also means that planning agencies should have access to a wide variety of talents.

"Especially at the level of the state governments, planning and resource management agencies are often understaffed and underprofessionalized. Many state agencies are ill supported and ill prepared to discharge their rather considerable planning responsibilities, and are staffed to carry out little more than token reviews of plans prepared by local, private, or federal agencies. It is essential that state agencies be staffed to discharge their water resource planning responsibilities competently; the alternative is abdication by default."*

*(From *Regional Development and the Wabash Basin* edited by Ronald R. Boyce, University of Illinois Press, Urbana, Illinois, 1964, 224 pages; Chapter 9 by M. E. Marts, "Conflicts in Water Use and Regional Planning Implications," pp. 145, 155.)

Competition for Water

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Economics of Competition for Water

Each day something like 300 billion gallons of fresh water is withdrawn for use in homes, factories, businesses, or on irrigated farmland. These quantities are withdrawn from water courses, kept in circulation sometimes for several cycles of re-use, and then either returned to a water course, which may be a ground water aquifer, or depleted into the atmosphere. Some water is, of course, embodied in the products of manufacture. There is both immensity and great diversity in the uses we make of the water we withdraw from our lakes, streams, and underground aquifers.

Other huge quantities of water are used on site for diverse purposes including transport of certain articles of commerce, carrying off wastes, maintaining sport and commercial fisheries, water fowl and furbearer populations, generating hydropower, providing the media for pleasure boating, and providing pleasant scenery.

The perennial crop of economic and population forecasts makes us aware that a growing national economy such as ours will eventually be using even vaster quantities of water than we are using today. It is not my purpose here to speculate on the size and composition of our demands for water by any certain date but rather to emphasize the problems of choice which our growing demands for water pose for us. In reacting to these problems, we have choices both in shaping the future demands for water and in charting a course for satisfying those demands.

First, I want to establish a general viewpoint toward the competition for water in two senses, in the sense that our desires for water compete with our desires for other goods and the sense that particular water uses may compete with each other. We may call these two senses competition in the large and competition in the small.

Next, I want to set some goals for resolving both types of competition for water and to establish the public nature of our water problems. In a word, I will argue that while we have a public water economy rather than a private one, we nevertheless can adopt the goals of economic efficiency in the management of our water economy.

*The views expressed are those of the author and not necessarily of his organization.

Finally, I want to discuss some techniques for managing the water economy against the background of a current problem in the Potomac River Basin.

The Nature of Competition for Water

Certainly the amount of water surface in lakes and streams and the run-off from our watersheds will be less per capita in the future than they are now. This may not be a relevant observation, however. Such an analysis inevitably leads to the conclusion that by a certain date we will bump against a water ceiling limiting the growth of population and economic activity. Such fears do not appear to be well grounded for the reason that man's ability to discover new technologies and to adjust his laws and institutions to new needs have been able, up to now, to prevent any significant group of natural resources from becoming so dear as to throttle our development and growth.

To the extent that there are more competing claims for water, however, a certain urgency exists over the question of how well we resolve these claims. The stakes of management become higher as water becomes less of a free good. We can see the evidence for this fact in those regions and localities where water of adequate quantity and quality is perennially or even occasionally inadequate to meet all claims. We must therefore be as careful to guard against the euphoria of over-abundance as against the phobia of dire scarcity. The problem is that there are coming to be more costs associated with the problems of getting desired quantities of water of desired quality to the right place at the opportune time. The costs may be expressed as other uses of the water which have to be foregone or impaired in some way. This is competition in the small.

The technical relations between the uses of water are an appropriate beginning for discussing the competition for water in the small, that is, for treating cases of conflicting uses for water. To get hold of this question, I will try to adopt a general framework. This is a bit difficult to do because of the ubiquitousness of water, the great variety of uses to which water may be put and the complex interrelations between the different uses. To a great extent, the interrelations between uses are so significant and complex because water tends to be a continuous medium capable of translating upstream effects downstream or pool effects laterally, and because withdrawal uses have consequences both on the quantity and quality of return flows. Moreover, since water is subject to both withdrawal and onsite uses, we must deal with interrelations between two major categories as well as relations within categories. The addition of this dimension triples the number of interrelations which can exist between uses.

There are some general categories for handling the interrelations between different uses of water. Any pair of water uses may be technical complements or technical substitutes. If they are technical complements, then one use enhances the other. The creation of a water area for a waterfowl refuge may also produce some increase in the fish population and in furbearers. Also, increase in the flow of water at one point in a stream may enhance uses downstream.

By contrast, technical substitutes are uses which conflict with each other to some degree. Some uses may be highly antagonistic. For example, water diverted to irrigation use is depleted by about 60 percent of its volume—of every million gallons put on the land, 600,000 gallons are evaporated from the soil surface and transpired from plants and only 400,000 gallons eventually return to the water course. Water diverted from an industrial process may be returned to the water course undiminished in flow but its usefulness for other purposes may be completely destroyed. Other uses may be only slightly competitive. For example, power boating on a lake may impair somewhat the usefulness of the water surface for fishing or swimming; both uses may be impaired by moderate drawdowns in the reservoir in order to generate hydroelectric power or to provide water supplies downstream.

To the extent that complementarity or independence exists between uses the common phrase "multi-purpose use" may be applied without causing any difficulties. When complementarity exists and both uses have positive value it is generally desirable to develop one or the other use at least until the complementarity is exhausted and they become independent. To some extent recreational use is complementary with the creation of a reservoir for nearly any purpose but such complementarity may be easily exhausted by only a little recreation and then the uses become competitive.

When uses become competitive with each other then we cannot be glib about the desirability of multiple use. It is entirely possible that the best solution to some competitive use problems is the devotion of the water in question to a single purpose use. This may mean that certain streams are best used solely for the carrying of wastes while others may best be dedicated solely to free flowing river recreation. It may mean that some reservoirs should not be developed for recreational uses which will require the setting of limits against drawdowns but should be drawn down unrestrained by recreational interests while other permanent level reservoirs should be dedicated solely to recreation, perhaps to even certain kinds of recreation.

To grasp the problem of competition for water in the large, that is in terms of over-all sufficiency of supply, we have to elevate to some economic relations. When we do this we find that we are no longer able to discuss the competition for water, as competition for water. We are able to have as much water as we want any place we want it for any purpose so long as we are willing to pay the necessary price. The competition is not for water but for dollars, for the investable funds which any program for developing and using water might demand.

In reality, all competition for water, both in the large and in the small, is reduced to an economic competition in which our criterion for resolving conflicts can be economic efficiency. Economic efficiency requires that we make the best use of our dollars as between water and other demands and that we make the best use of our water as between competing uses.

Resolving problems of competition between uses requires two kinds of information: Information on the technical relations between uses and information on the additional value accruing to society from having more of either use. Resolving problems of competition between public investment in water and other public and private investments requires the same sort of information between water and its competitors. The question is what means do we have for collecting and acting upon such information?

Managing the Water Economy

In order to find a unity for dealing with such problems of competition, we must turn to the realm of ideas to develop some principles regarding the existence and operation of the water economy. From here I propose to return to some actual problems and draw some conclusions as to how the choices might be approached, both in terms of instruments and institutions for dealing with them.

The first idea concerns the Water Economy. The water economy, unlike the steel economy or the lumber economy is largely a public economy. We do not have public meetings for the purpose of discussing the problems of conflicting uses for steel or lumber. The reason is that conflicting demands for these commodities are resolved in the market places of the private economy. Such conflicts are resolved by the active bidding of users against each other for limited supply of the material. Such bidding sets a market price which excludes all those who are unwilling to pay the market price for particular uses of the commodity. Now this may mean that all users get some of the material but none get any more than they are willing to pay for. We believe that the market works well in allocating steel, lumber, and thousands of other commodities to the best, i.e., economically most valuable, uses. The great virtue of the private markets is that they accomplish an enormous amount of decentralized calculation and decision-making that would otherwise overburden central authority.

Why is the production and distribution of water dealt with in the public economy and not in the private economy? The first reason is that those who would invest in the production of some kinds of water services cannot be assured of capturing the full value of their products. Consider the problems one would have in excluding his neighbors from enjoying the benefits of a flood protection reservoir he might erect for the protection of his property. The second reason covers the obverse case; that is, there is no way the private market can impose upon a polluter the downstream costs of his waste discharges. Together, these two reasons cover most of the rationale for the existence of a public water economy. In sum, water services are produced publicly because of the common good which such services produce and because of the economies realized from coordinating upstream-downstream relations.

Other reasons for public investment in water resources can be covered by saying that the investment requirements for an efficient scale of operation are often too large for private firms to finance (think of TVA), sometimes they are too risky for the private economy and sometimes there are public intentions to subsidize certain regions of certain groups of water users. This is not to say that all water services produce common goods nor that public entrepreneurship always guarantees the best solutions to our problems. In fact, we can now examine some disadvantages of our public water economy and in so doing raise some issues which bear on how we might deal with emerging water problems.

In the first place, we must recognize that in the public economy the political process largely replaces the market process. While we do not want to ignore the imperfections of the market process, it is appropriate here to call attention to some of the imperfections the political process has in dealing with our water problems. The political process involves bargaining in which the ability to walk off with a purchase is not so dependent on willingness to bid up a money price as it is on ability to operate strategically. The bargaining for water resource projects in the Congress has come to be known for better or worse as the pork barrel. The water resource agencies have their own kind of bargaining process in which the water resources budget may not serve the criteria of efficiency either in total size or composition. Moreover, tradition is of enough consequence in government as elsewhere that programs are perpetuated on their own momentum long after their services have ceased to have any value.

Among other costs of our way of doing business in the public water economy, one certainly is that the initiative and the ability to plan and carry out water resource programs has been concentrated in the federal government. The federal monopoly on an impressive array of technical talent has meant that the state and the regional role in water resource management has been sporadic at best. While the federal government may be more responsive to the needs that have been articulated in water resources, and therefore justly deserving of its preeminence in this field, it also may be that greater participation in water resource planning by state and regional bodies can result in greater inventiveness in locating solutions to problems and greater fidelity to state and regional preferences.

Our approach to the flooding problem illustrates the potential role of more localized planning and action. Traditional choice in flood plain use has been between (1) flood protection and (2) bearing the loss without other adjustments. By flood protection I mean resort to dams and levees.

Increasingly there has been attenion paid to other possible adjustments such as comparing costs of using sites outside the flood plain with costs of development in the flood plain. Other alternatives are flood proofing (which is a combination of emergency evacuation and changes in structures), insurance and watershed treatment. Now land use adjustments in the flood plain are particularly suited to local initiative but such alternatives will not be perceived unless there exists an organization for gathering and analyzing information at the local level. Appropriate state or regional authorities might do this and might in the process inject some healthy competition into the state-federal planning relation.

Creating more planning initiative to countervail the federal agencies answers only a part of the problem. With the concentration of responsibility for water resource programs at the federal level of government and the separation of decisions from any market process has also come a divorce between the beneficiaries of projects and the responsibility for ultimately paying for them. This means that willingness to pay by the consumer does not carry the weight in public decisions that it has in the market place. Under these circumstances the public solution of water resource problems becomes subject to biases in which only those measures eligible for federal money are considered and at times the process approaches a bald raid on the federal treasury. To correct such biases all measures might be eligible for the same degree of federal financing and financing might be available to federal and non-federal authorities. A more important correction to such biases might involve greater use of user charges and higher charges to more nearly cover the costs of the service.

Now a word about the general goal of economic efficiency in the water economy. Efficient means precisely that we seek solutions to our water problems which maximize the net benefits of the planned expenditure, or if benefits are not measurable then we seek the least cost means of achieving a particular result. Besides adopting the goal of efficiency, I am working from the postulate that decentralization of the enormously detailed calcuations necessary to achieve efficiency is a necessity in the water economy. My model here is a properly safeguarded private market.

The goal of efficiency in water resource programs when implemented by the benefit maximizing procedure known as benefit-cost analysis to the water agencies or by the cost minimizing procedure known as "cost effectiveness" in the Defense Department induces us to follow rational behavior in our investments in water resources. Another way of describing what is involved is to say that we are economizing. To economize on water resource investments is both to make the best use of limited funds for water resource development and also to make the best use of a given water resource. The opposite of economizing behavior is squandering in a manner which does not give us the greatest possible benefit for the resource expended. We tend toward squandering when we come up with plans which say we must have X million acre feet of water for such and such a purpose in such and such an area by such and such a time. The Senate Select Committee on Water Resources a few years ago asked the water resource agencies to estimate future needs in their areas. This resulted in a congeries of requirements that say we can spend another 22 billion dollars on reclamation projects, another 8 billion on navigation projects, another 6 billion on flood control and 15 billion by 1980 on a new investment purpose called low flow augmentation, which means providing water for waste disposal and water supply during periods when natural flows are low.

Were we to completely fulfill such requirements over the next 20 or 30 years, it would be done at the expense of better schools, better health care, at the expense of continued blight in our central cities and continued neglect of our depressed rural areas. Unless the federal budget becomes vastly larger, these are the real costs of the requirements approach to any public expenditure.

We cannot make wise decisions either in the water economy or in public expenditures of other kinds by simply proclaiming requirements. Instead we must develop information on how much it is worth to have more water in a certain place at a certain time and how much it costs to achieve the result by the lowest cost means. Such information comes only from fairly elaborate analysis which can improve our choices by such a margin that it is worth more widespread use. Even here we must recognize that information costs money and there must be a limit to the expense we are willing to absorb in order to improve decision-making. Some examples from my current research hopefully may illustrate the kind of result attainable by more elaborate analysis.

The Case of the Potomac

The Potomac River flows through the nation's capitol from the hinterlands of Virginia and Maryland as virtually the same pastoral river known to George Washington. The growth of the Washington metropolitan area and of certain industrial areas is catching up with this natural river, however. In a matter of 10 or 15 years the natural low flow of the river will be unable to meet Washington's daily water supply withdrawal if this withdrawal grows at projected rates. Moreover, at various times over the next 50 years certain parts of the river, the foremost of which is the estuary at Washington, stand a chance of becoming obnoxious during low flows because the waters will not be able to assimilate the expected quantities of even highly treated sewage effluents and at the same time maintain a pleasing quality. The Corps of Engineers has proposed a system of 16 major water storage reservoirs on the Potomac and its tributaries in order to maintain sufficient flows during times of drouth so that water supply withdrawals can be met and water quality maintained up to standard. Flood control storage is significant in two of the reservoirs and in addition the Soil Conservation Service has proposed an extensive system of headwater reservoirs for flood control and low flow augmentation. The major reservoirs especially, would also be expected to provide substantial amounts of outdoor recreation for the surrounding populations, so much so, in fact, that nearly one fifth of the total investment cost of $495 million would be spent on recreation lands and facilities adjacent to the reservoirs. One of the reservoirs, being very close to Washington, would be expected to ultimately sustain 7 million recreation visits annually. This reservoir is the subject of a heated controversy because it would inundate 30 miles of the C. & O. Canal Towpath and a like amount of natural river. This 30 miles currently sustains a significant amount of recreation, albeit a different kind of recreation than that afforded by a reservoir.

There is little room for disputing the Corps' diagnosis of the water problems of the Potomac Basin. The low flows of the river will eventually be inadequate in places to accommodate withdrawal demands and water disposal requirements unless something is done. The question is what should be done? The question is a general question which applies to most of the rivers in the humid East where sooner or later these same problems will occur. Unlike the arid West where water supplies are totally allocated, if not over-allocated, the humid East has plenty of water for meeting withdrawal requirements most of the time, and with a little storage and regulation can meet demand nearly all of the time. The problem will be to minimize pollution costs in water which flows by city after city and factory after factory.

Let's ponder how we might approach the question of what should be done in these circumstances. In the first place the predictions of municipal and industrial water shortage are based on certain projected water use rates. These are projections of physical quantities which have no relation to future costs of water. If water use projections were to be made under conditions of rising costs of supply and with the proviso that users would be expected to pay the supply price, water withdrawal rates might turn out to be significantly different from projections which assume essentially free water. When water becomes sufficiently dear industries can afford to reclaim and recirculate process and cooling water and homeowners stop using water to flush grass clippings off lawns or to irrigate lawns profusely. It is even conceivable that in certain areas dual water systems can be justified which would circulate very costly supplies of potable water for human consumption and lower grade water for other uses.

It should be noted here that the introduction of pricing policy for water to meet the costs of the marginal quantity supplied is a device which cuts two ways: It rations the supply by forcing out the low value uses and it informs the supplier of the consumer's willingness to pay for additional quantities supplied. We shall mark this use of price as the first point at which a device of the private economy might be transferrable to the public economy. In another application price might be applied to the problem of waste disposal as follows: The use of a stream for disposing of wastes is both a valuable service and an act which imposes costs downstream. If waste dischargers are charged for the costs they impose on others they will have an incentive to reduce pollution up to a point where their additional costs of pollution reduction are offset by the additional savings in effluent charges. If a rational polluter chooses to pay the charge rather than reduce his waste discharge this tells us that it is best for society to bear the costs of his pollution, whatever they may be.

A very important aspect of the demand for water services concerns the level of water quality we wish to achieve in our water courses. In the Potomac Estuary, as elsewhere, we are forced to rely upon standards in making our choices. Several aspects of our standards make it difficult to defend them as efficient choices.

In the first place, standards which say that the dissolved oxygen should be 5 ppm in the Potomac Estuary are arbitrary numbers which are arrived at without adequate knowledge of the consequences of not meeting the standard some of the time or all of the time. Nor is there an attempt to consider what we might be losing by not having a higher standard. It might also be useful to know how much less it would cost in waste treatment plants or reservoirs to adopt a lower standard. For example, we might willingly invest $10 or $20 million but not $50 million to raise dissolved oxygen in the Potomac Estuary from 3 ppm to 5 ppm.

The second difficulty with standards is that they are largely technical judgments which are arrived at by engineers and technicians. While we are indeed fortunate to have experts who are willing to take such judgments on themselves, we must also wonder if they are basing their judgments on the really important criteria and if their judgments are really what society would prefer if it were fully informed and able to exercise a choice. Perhaps it is not dissolved oxygen but the color of the water which is of real interest to those who use the Potomac Estuary. If clear blue or green water is preferred over the turbid greenish-brown water now found in the estuary then siltation and plant nutrients are the pollutants we ought to be concerned about and not organic sewage. Moreover, we could well look for a means for making such choices that does not depend, as we do now, on the planner's choices. In this connection the regional river basin authority has some merits worthy of discussion.

Whatever water quality goal we choose, the dictates of efficiency require that we find the least cost means of achieving the goal. Low flow augmentation is the proposed remedy for the quality problems of the Potomac. In order to make the point that flow augmentation is the least cost remedy for a water quality problem, one needs to test a range of alternatives in various combinations. This our research is doing in the hope of demonstrating the value of the analytical approach. The alternatives are of three kinds: Higher levels of waste treatment; mechanical reaeration; and diversion of wastes to points where the river is more capable of handling them.

Conceivably we could discover that there are less costly systems for solving the quality problem than the one officially proposed. Such a least cost system might include using some very high level waste treatment for only short periods during the year, some diversion of wastes to other points and some reservoir storage for low flow augmentation. The question then will be why the federal planning effort did not discover such a solution. Two possible answers can be found. One is that inadequate knowledge exists on advanced waste treatment or even on the effects of redistributing waste loads in a body of water. This suggests an intensified research effort. The other answer, possibly the more significant one, is that there is neither the planning authority nor the financial incentive to give serious consideration to the waste diversion or waste treatment alternatives. There is no mechanism by which to make the decision that the local governments in the Washington Metropolitan area will operate high level waste treatment or divert their wastes from the critical parts of the estuary. Nor is there an operating authority which would coordinate such a move. Finally, the local governments have good cause to be disinterested in such alternatives for the reason that they would pay the full costs of such actions, whereas solving the same problem by low flow augmentation is 100 per cent federally financed.

Clearly both situations are defects in our current planning, if, as we now suspect, there are better choices than the proposed remedy. The defects cannot be cured unless the authority and financing of the agencies is extended to a bigger arsenal of tools or unless regional planning authorities with equal scope and financial backing can be created to meet such problems.

Finally, the planning for recreational use of water presents at once the problems of a rapidly growing demand and a paucity of information on that demand. Whereas, matters of water supply, flood damage reduction and to some extent water pollution deal with consequences for which there are economic measures, there are as yet no economic measures which adequately reflect the social values of additional water for rcreation. We need such measures not only to plan wisely for recreation *vis-a-vis* other uses of water, but also to plan for the best combination of the various recreations.

The proposal for the Potomac Basin will again serve as illustrative material for two kinds of issues in recreation planning. First of all, at least two of the reservoirs in the proposed plan will obliterate all opportunities to enjoy popular reaches of natural rivers. Our present structure for planning recreation in connection with river basin development does not permit a positive treatment of natural recreation opportunities. At best we can only avoid destroying them.

Even if we were geared for positive treatment of natural rivers we would be hard put to find the data on relative values of river versus reservoir recreation from which to argue the choices.

Secondly, we have not even the feeblest means for evaluating a plan for recreation development tied to a reservoir system in a basin which has a wealth of potential recreation investments, not only on natural rivers but on the shores of estuary and ocean and in some of the most primitive mountain forests of the East.

The need for better information on the preferences of recreationists, including their willingness to pay for the recreation benefits they receive and on the costs of supplying the various kinds of recreation opportunities is apparent.

Conclusions

My conclusions from this discourse are that we must meet certain needs for analysis and organization—the two are mutually dependent—if we are to successfully meet the challenges ahead in arriving at efficient solutions to the competition for water for the public water economy. The competition we are concerned about is competition for dollars, first of all, to be invested in water resource development. It would be unwise to yield to the scarcity phobia and over-invest in water at the expense of other public or private goods.

As for competition among water uses, or competition in the small, we must be concerned first with taking full advantage of all complementary uses of water and second with allocating water among conflicting uses in a manner which yields the highest possible benefit to society. While efficiency may be our primary goal, there is room for compromising efficiency in order to serve the ends of equity or fairness.

Certain approaches merit consideration as we tool up for the job confronting us. In general, we need to examine the virtues of the decentralized decision-making that takes place in the private markets with an eye to using quasi-market devices to resolve competition in the public water economy. Specifically:

1. There may be real benefits from enlarging the state and regional role in water resource planning and management if this can be done without spreading the qualified people too thinly. Alternatively, we can expand the arsenal of tools available to the federal planners. In either case the goal is that all potential solutions to a problem be considered and not just a few which happen to be federally subsidized.

2. We must be prepared to enter into much more elaborate analyses of water resource systems in which more and better information is developed in the planning process and used to perceive a range of alternatives so that the choices available to us have some real variety and content.

3. In turn, the organization for making choices must be able to function effectively so that the planners themselves do not end up making the choices.

4. Particular information problems exist: (a) on predicting demands for various water services in a way which incorporates feed-backs from the supply costs, (b) on developing techniques for waste treatment and industrial use in response to the new problems, (c) on measuring recreation demands and bene-

fits, and (d) on the alternative legal and institutional conditions that affect the efficient performance of the water economy.

5. There is much to be gained from associating charges with users who benefit from a water service, be it water supply, waste carriage, navigation, or recreation. Charges based on costs, and preferably marginal costs, serve to allocate water to the best uses and to put realistic limits on demands. Free water services by contrast encourage uneconomical uses and unlimited demands or "requirements."

In sum, if the goal of rational, economizing behavior is accepted then we need to continue to improve in these directions the means by which the public water economy resolves the competition for water.

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Role of Water in the Development and Growth of Missouri

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Water is a pervasive subject. It concerns so many interests that developing a program covering all of the aspects related to it is quite difficult. As you reviewed the program for this Forum no doubt some of you noted gaps. However, the topics listed are such that a full day's discussion could be devoted to each.

It's indeed a pleasure to welcome you to this Forum. I'm delighted that you can be with us. As you know, we've had Forums in past years. Although the format for this one is different I'm sure everyone will gain from having participated. I'm sure also, that we here will gain much from your participation. I have every reason to hope that our understanding of the total information pertaining to water will be much greater as a result of this experience here to-day. I think the value of the discussion will help us all with our conception of the role of water in our state's growth.

May I have the privilege of rambling? My topic is "The Role of Water in Missouri's Economic Development and Growth." I don't believe I can cover this adequately, and I doubt if we have sufficient understanding of all the facets necessary to place water in its appropriate role as a factor in the growth of Missouri.

Of the necessities of man, water is most vital. Water is one of the most abundant and widely distributed substances—a chemical compound, H_2O, which is an essential constituent in the cells of all animal and vegetable tissues and in the crystals of many minerals. Water is a physical standard of comparison such as with specific gravity-viscosity. Water serves as a catalyst and as a solvent in science and industry.

Water has many many facets which have literally figured in the history of civilizations and in the growth of nations and their commerce.

With water generally available and so widely used one would be tempted to conclude that of all our resources water does not represent a matter for real concern. Yet we are concerned, are we not? The real concerns involving water are associated with population growth.

Someone has calculated that in our country approximately 1,500 tons of water—fresh water—are used to support one person annually. Of all the other materials, food, fuel, plastics, metal, lumber, sand, gravel, we require only 18 tons annually per person.

Water outweighs by far everything else we consume yet very little of it costs as much as a nickel a ton.

From this it would appear that surely there is plenty of water and at low cost.

But all of us know concern is widespread, not only in this state but over the world. Water, from several points of view, has become a scarce resource and one which ultimately is a subject of public policy discussion and debate. This widespread concern results from the rapid population growth which affects water usage in several ways:

First, more is obviously used directly.

Second, more is required or affected by food production to feed the extra people.

Third, more is used in production of other goods and services for the expanding numbers of people.

The last two usages are affected additionally by the level of living or affluence of society. For example, water usage goes up for many manufacturing processes such as in chemicals, paper, pulp, and oil and utilities.

More is used in some form or another for recreational purposes as our society can "afford" time for recreation.

Food supplies, the world over, have been and will continue to be influenced by water supply.

World wide, water will have a key role in agricultural production. A billion persons have entered the world since 1940. Food production for a greater population requires greater efficiency and additional development of new regions. Water makes possible full use of technology in production. It surprises me that 13 percent of arable land in the world is under irrigation. Nearly two-thirds of the irrigation in the world occurs in Asia. Twenty percent of the cultivated land in India is irrigated, 16 percent in mainland China.

In our country we are not so dependent on irrigation, although more than 10 percent of our cultivated land is irrigated. It is the heaviest single user of water; most of it is in the western states. Water used in irrigation is almost 10 times that for all other uses in the west. The limits of supply are in sight in the west. In contrast we are favored with a large water supply in this section due to our location within the Mississippi basin.

What are problems associated with water use and development in this state? These are questions that will be discussed in this Forum today. I shall review some—

1. Is it possible to improve economically the imbalance in water supplies between northern and southern parts of Missouri?
2. How do we improve quality of water? How do we reduce pollution from various sources? Can we attract industrial development yet maintain appropriate public control of pollution?

3. To what extent can we economically improve recreational uses of water? Does this use have the prospect of improving income potential of our state? The millions of outboard motors, boats, swimming pools and similar items related to water recreation that are produced each year are definitely a new income source.
4. To what extent can agricultural output be economically increased in this state competitively with similar regions in this country?
5. Will we continue to have rights to water from rivers along our borders? Will upstream use and allocation affect us adversely?

These are only a few of the questions which can be raised in a discussion of water. These kinds of questions lead us to the complex problem of allocation among competing uses. It invariably raises a series of questions involving public policy.

We are hopeful that the Forum today will encourage thought and discussion by all who are interested in these matters.

Much is at stake in Missouri, for the water resource probably is among the less intelligently used resources within our state.

The University of Missouri is participating in the national research program related to water resources. We are pleased that this institution has been approved, based on our proposals, as one of 14 universities to begin work immediately in the vital area of water research.

This Forum will no doubt contribute to making our water related programs more meaningful. It should lead us in coming to grips with the concerns that the citizens of this state have for our water resources. We are most appreciative of your interest and your participation in this Forum. We are grateful to you for your attendance and particularly your contributions to the general understanding of the role of water as you discuss its various aspects with your friends and neighbors.

Best wishes for a successful conference.

Pesticides: A Current Water Quality Problem

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Water is often referred to as the universal solvent. As such, it might be thought of as a rather thin soup containing various dissolved and undissolved organics and mineral washings from the land, and also, municipal and industrial wastes resulting from man's endeavor.

Public health authorities traditionally are concerned with water quality. During the past 25 years dissolved organics have assumed increasing importance as water contaminants, and today strenuous efforts are being made to measure and identify the specific organic substances found in water. They are legion, including a number of modern pesticides.

What Is Known About Pesticides in Water?

Pesticides occur in surface water by means of land runoff, accidental application, and by deliberate application to control undesirable plant or animal life. They also sometimes are components of manufacturing wastes.

Breidenbach and Lichtenburg, in 1963, reported the recovery of DDT in nine rivers in the United States and the presence of dieldrin in the Savannah River at North Augusta, South Carolina. (1).* Endrin occurrence in the Mississippi River in late 1963 received widespread press coverage. Our own studies have recorded, in addition to the above, the insecticedes TDE, toxaphene, BHC, parathion, and diazinon, and the herbicides 2,4-D, fenac and 2, 4, 5-T. (2). If analytical methodology were as sensitive and refined for all pesticides as they are for these halogenated organic and sulfur containing organophosphate insecticides, perhaps the list would be longer. However, methodology is not sufficiently refined and consequently we currently are unable to detect, in the parts per billion or less range, many of the pesticides that are used in a manner that experience has taught us might result in land runoff and appearance in water.

*See numbered references at end of talk.

What about land runoff? When a pesticide is applied in the field it may appear in water running off the land in solution or adsorbed on soil or other solid matter that is transported by the water. Heavy flushing rain may result in the sudden occurrence in the receiving stream of an overwhelming toxic concentration sufficient to kill fish, and this may pass downstream as a slug. Many farmers have experienced loss of the fish in their farm ponds from this cause.

More normal, however, is the frequent periodic (one might say almost continuous) contribution from the land of pesticides in concentrations usually less than one part per billion. This does not result in obvious harm and goes unnoticed. Studies since 1959 in the Flint Creek drainage basin of Alabama, a 400 square mile cotton producing area, have demonstrated this phenomenon (3, 4). Seven-day carbon adsorption samples are almost always positive for toxaphene and BHC the year around.

That the nature of the pesticide itself is a factor in runoff is shown by the fact that DDT, which is applied annually in the Flint Creek Basin in greater quantities than is BHC, seldom is recovered from Flint Creek water. This relates to the lesser solubility in water of DDT than either toxaphene or BHC and to its greater non-polarity that causes it to leave water preferentially in favor of soil, sediment, or other substrate.

Ground water also may be contaminated by pesticides. An outstanding example of contamination by percolation through the soil occurred in the South Platte River basin near Denver, Colo., from 1951 at least until 1958 (5). Phytotoxic substances, including 2, 4-D, apparently seeped into the ground from an industrial waste lagoon. Well water was ultimately contaminated over a 6.5 square mile area to a degree sufficient to produce an undesirable taste in farm well water supplies and to cause crop damage when well water was pumped for irrigation purposes.

Parathion was found in water from municipal wells of a Florida city over a period of several months in 1962-3. The concentrations were usually less than one part per billion and all five of the city's wells were involved as well as several test wells in the vicinity. The source of the parathion was not found although water taken from canals in the area also contained parathion. It was speculated that this, too, was a case of percolation.

What Problems Are Created by Pesticides in Water?

The most obvious problem caused by the occurrence in water of pesticides is the death of fish and other aquatic life when the pesticide concentration is sufficiently high. This concentration for acute lethal effect will vary from about one part per billion or less for endrin to 180 parts per million for Dipterex, and even greater for some of the less toxic (to animals) fungicides and herbicides (6). The annual summary reports of Pollution-Caused Fish Kills prepared by the Public Health Service indicate that 13 to 19 percent of 400 to 500 fish kills reported annually from 1961 to 1964 resulted from "agricultural chemicals" getting into water.

Another problem is the effects of long-term, subacute exposure of aquatic life to pesticides. Part of this problem is the fact that the problem itself is not at all adequately understood. Adverse effects of such exposure are obscure. It is known, however, that a process called biological magnification occurs involving the chlorinated hydrocarbon insecticides. In this process small quantities of insecticide are absorbed or adsorbed by basic components of the food chain and are passed on to the larger forms of life that feed upon them. The concentrations build up in the consumers and are, in turn, passed on to higher forms of aquatic life. Eventually fish are found that may have several hundred parts per million of an insecticide or several insecticides stored in their fat. These fish may be seemingly healthy as was one that we obtained recently from the Tombigbee River in Alabama whose liver contained 2.1 ppm of toxaphene, 0.99 ppm of DDT, 0.08 ppm of dieldrin, 0.07 ppm of endrin, and 0.04 ppm of BHC. There is no evidence that this fish ever would have been harmed by the presence of this array of insecticides. Insecticides in storage in fish are not immediately available for involvement in the metabolism of the fish. But what happens when the fish is put under stress such as starvation or spawning when its stored energy must be utilized? These questions are now under study at a number of institutions.

Two examples come to mind where biological magnification has caused indirect adverse effects. In the first, overwintering grebes (a migratory fish-eating waterfowl) were poisoned on Clear Lake, Calif., from eating live-caught fish in whose tissues the insecticide TDE had accumulated (7). The second resulted in almost total loss of lake trout fry at the Lake George, N. Y., fish hatchery whose source of eggs was fish taken from Lake George (8). In this instance the eggs hatched successfully but the fry died as the final contents of the yolk sacs were being absorbed. Subsequent investigation showed that the adult female fish and eggs contained DDT and that fry hatching from eggs that contained 2.95 ppm or more of DDT would not survive. One may well ask, what other subtleties of biological magnification remain to be revealed?

Finally, there is the problem of municipal water supply involvement. The national trend in municipal use is toward surface sources of supply as the ability of local ground water aquifers to produce is exceeded. Surface sources of water are, of course, most likely to become contaminated by pesticides, and there is no way for a water plant manager to become aware of this comtamination except by costly routine monitoring by analytical means or unless the concentration is sufficiently high to kill fish. Recent work at the Robert A. Taft Sanitary Engineering Center of the Public Health Service in Cincinnati, Ohio, has shown that activated charcoal can be used efficiently in reducing the concentration of a number of insecticides if encountered in municipal water supplies (9).

What Is Being Done About the Problems?

Efforts by public agencies and the agricultural chemicals manufacturing industry are being made to find solutions to these and other problems. Emphasis is being given to research to find new methods of pest control not involving pesticides and to develop more selective pesticides.

A greater awareness of public responsibility is now evident among all groups involved with the production, distribution, and use of pesticides. For example, the formation of a special committee (The Grady Committee) charged with the responsibility of developing principles of good practice for pesticide manufacturing and the disposal of empty containers and plant wastes, was announced November 17, 1964, by the National Agricultural Chemicals Association.

At the same time public educational efforts have been expanded to bring about safer use of the pesticides we now possess. This effort must be carried on continuously if all of the people are to be reached. As recently as December, 1964, 50 four-pound bags of 15 percent parathion were disposed of by dumping them into a small river only a mile upstream from the water supply intake of a town of about 5900 people in Florida. Behavior such as this that might endanger the health of others cannot be tolerated.

Considerable sums of money are being spent on research, notably by the Federal Departments of Health, Education and Welfare; Interior; and Agriculture; by universities through various grants programs; and by states to gain further knowledge concerning the occurrence of pesticides in water and their impact upon the environment. Our research at the Southeast Water Laboratory is designed, within the context of over-all land drainage studies, to cast further light on soil-pesticides relationships as they pertain to retention or failure to retain specific pesticides on the land, to elucidate the nature and identity of pesticide metabolites and decomposition products, and to determine the impact of specific compounds on living organisms at the cellular level. The new information gained from this research will be used to formulate water pollution control measures.

Our third problem was pesticides in municipal water supply. Research continues, notably at the Robert A. Taft Sanitary Engineering Center in Cincinnati, on better means for removal of pesticides in the municipal water treatment process. Although there is no record of adverse effects upon humans from consuming pesticides in drinking water, we must consider this as only one source of human exposure. Studies are currently underway, sponsored by the Public Health Service, to evaluate the effects of total environmental exposure upon the human subject.

Discussion

Pesticides have been in use for many years, but the wide usage of synthetic organic pesticides beginning about 1945 is the source of considerable public anxiety. This concern is not entirely without cause, although it may be, insofar as water is concerned, that the charge against pesticides in general should more properly be leveled, with some exception, against the chlorinated hydrocarbon insecticedes alone. They are, in general, the most toxic of the pesticides to aquatic life; they are, as a group, very stable compounds whose ultimate disposition in the environment is difficult to control; and they become stored in living organisms where they are unwanted. Therein lies the crux of the problem and it bears a striking resemblance to the problem of radioactive fall-out.

Perhaps the interim solution to the pesticide problem, like that of radioactive fall-out, will be brought about by the citizenry through their elected representatives. If such is the case, the solution will be based upon a balance between the hazards (real or potential) of pesticides that we are willing to accept in relation to the very real benefits that are to be derived from their continued use. It is the job of the researcher to provide the factual information that the public needs in order to make this decision while he continues to work toward the development of solutions more nearly satisfactory to all.

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Pollution From Industrial Wastes and Sewage

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Any attempt to consider the many facets of water and its quality necessarily must include pollutional aspects of municipal and industrial wastes. The purposes of this presentation are to provide some perspective of the over-all problem, to indicate significant areas of need, and to discuss selected specific problems.

Waste streams of inferior quality are described as being polluted, but we must not overlook the many benefits to man and his activities provided by utilization of this water. Certainly the most effective method of minimizing pollution from municipal and industrial sources is to eliminate the populations and industrial pursuits creating the waste streams. Since this hardly can be considered a desirable method, we must accept waste streams as inevitable consequences of man's existence and activities. An increasing population, a tendency toward urbanization, greater industrialization, a growing awareness on the part of the public, and the pronounced desire to maintain adequate quality in our waters no longer permit releases of untreated waste waters to our streams.

Waste disposal without treatment may be considered as being an obsolete practice except in extreme situations. An illustration of this point is provided by that portion of the Missouri River flowing through the State of Missouri. No longer than ten years ago, the accepted practice was to dispose of untreated municipal and industrial wastes by dilution in the Missouri River. Waste treatment facilities were not provided, and complete reliance was placed on the assimilative capacity of the river to prevent pollutional aspects.

A review (1) of the situation today, however, reveals that concerted efforts to reduce the pollution in the Missouri River have met with significant results. Some 98.5% of the urban population living in the indicated drainage area now has waste treatment facilities in operation, under construction, or at least financed. Many industries in or near municipalities choose to discharge their wastes into municipal sewers which results in treatment before release into the river. In addition, all known sources of industrial wastes with separate discharge into the Missouri River are providing some degree of treatment before discharge.

This change in attitude did not come about automatically, and data presented in Table I enumerate, by category, the waste treatment facility operating permits issued by the Water Pollution Board up through 1964. The importance of the waste stabilization pond—better known as the sewage lagoon—to the over-all program of water pollution abatement in Missouri is indicated by its use in over 1,000 separate instances. In fact, approximately nine out of every 10 waste treatment facilities in Missouri are sewage lagoons, probably as a result of the lagoon's low initial and operating costs.

Table I

SUMMARY OF OPERATING PERMITS (2)

Municipalities	282
Subdivisions	130
Schools	202
Motels and Resorts	296
Industries and Businesses	202
Other	60
Total Permits Issued	1,172

Results of a recent survey conducted to assess the effectiveness of waste treatment in major industries are summarized in Table II. Although results are expressed in a qualitative fashion, and the effectiveness was not determined in almost one-third of the cases, it should be pointed out that no cases are known of unsatisfactory conditions without corresponding remedial measures being initiated.

Table II

SURVEY OF INDUSTRIAL WASTES FACILITIES (2)

Classification	Number	Percent
Satisfactory	62	53
Improvements being made	21	18
Undetermined	34	29
Total Surveyed	117	100

The foregoing materials and remarks indicate that (1) treatment is now available or scheduled for wastes from all urban populations with but few exceptions, (2) treatment for wastes from industries in urban areas may be classified similarly, and (3) control over separate industrial wastes streams is being developed.

An appropriate objective of a first phase of water pollution abatement program is defined as placing all wastes of municipal or industrial origin under some degree of treatment before discharge. *It may be concluded that the first phase of the pollution abatement program in Missouri is approaching rapidly a successful termination.*

This conclusion, while valid, should not and must not lead to a dangerous complacency on the part of the public or of the regulatory agencies directly involved. Problems do exist, future problems can be anticipated, and many questions, to which satisfactory answers cannot be given at this time, can be asked. It is not enough to know that a waste stream is receiving some degree of treatment; we must determine how much treatment is given, if this degree of treatment provided is sufficient to meet the needs of the receiving waters.

The need for a second phase of water pollution abatement is suggested by such questions. The two-fold objective of this phase would be the prescription of water quality criteria objectives for Missouri streams and the institution of procedures and facilities for attaining such objectives. This program would incorporate, among other measures, intensive stream surveys, increased training for operators of waste treatment facilities, acceleration of research efforts, and determination of appropriate water quality criteria objectives for each stream in the state.

These observations certainly are not intended to reflect adversely on the Water Pollution Board or on its staff. To the contrary, one is justified in asking how so much could be accomplished in this short time under the imposed limitations of personnel and budget. A study recently completed by the Public Administration Service (3) a Chicago consulting firm, indicates both minimum and desirable levels of staffing and budgets for state water pollution control agencies. Application of the report figures to Missouri suggests, by comparison, the need for a four to eight-fold increase in the Water Pollution Board staff to meet the minimum recommendations of the study. More qualified personnel are needed sorely to augment the present activities of the Water Pollution Board.

Statistics on the 39 pollution related fish kills, involving an estimated 453,225 fish in Missouri during 1964, are presented in Table III.

Table III

1964 POLLUTION RELATED FISH KILLS

Cause	Fish Kill Events (4)	Approx. Number of Fish Killed (4)
Municipal and Industrial Wastes	12	49,650
Agriculture-Associated	19	83,525
Other	5	14,050
Unknown	3	306,000
Totals	39	453,225

The largest number of dead fish associated with a specific event was the 280,000 in the Missouri River fish kill of late May, 1964. A rigorous interpretation of data presented in Table III is not possible because of approximations in the numerical values and of the large number of deaths from unknown causes.

The reason for considering fish kill data is to indicate that the word "pollution" is subject to a number of different possible interpretations. Municipal and industrial wastes may play either a major or a minor role depending on what type of pollution is being considered. From the fish kill data it appears obvious that "complete" treatment of municipal and industrial wastes would not have prevented all fish kills, although certainly fewer fish would have been killed. This thought should be borne in mind when planning a broad-based intensive program of water pollution abatement.

If Missouri's 4,320,000 inhabitants were distributed uniformly over the state's 69,000 square miles (average population density of 62.6 persons per square mile) it is doubtful that water pollution from human wastes would be the same as we know it today. Municipalities have population densities of thousands or tens of thousands per square mile, the wastes are collected by sanitary sewers, and this large waste load is imposed on a given stream at one or more points. Stabilization or biodegradation of the wastes draws heavily upon the rather meager oxygen supply in the stream, and the nuisance conditions typical of pollution can occur if appropriate measures are not instituted. The oxygen required by the wastes in reaching a given degree of stabilization under prescribed conditions is termed the biochemical oxygen demand or, more simply, the B.O.D.

Dividing the oxygen requirements (lbs. B. O. D./day) of a given waste stream of non-human origin by 0.17, the value appropriate for human wastes, permits expression of a waste stream in terms of "population equivalents." For example, one fattening hog produces wastes equivalent to the wastes of 2.4 humans; i.e., it has a population equivalent of 2.4. Data on numbers of hogs and cattle in Missouri have been coverted to population equivalents in Table IV.

Table IV

POPULATION EQUIVALENTS OF SELECTED ANIMALS

Type	Number in Missouri, 1964	Individual Lbs. B.O.D. per day	Approximate Population Equivalent
Humans	4,320,000	0.17 (6)	4,320,000
Hogs and Pigs	3,997,000 (5)	0.41 (7)	9,640,000
Cattle and Calves	4,391,000 (5)	1.20 (7)	31,000,000

By comparison, although there are over eight million chickens (5) in Missouri, the corresponding population equivalent (8) is less than 700,000.

What is the significance of this array of data? It is a tabulation of *potential* pollution which will begin to be realized when large populations of such animals are brought together in relatively small areas such as feedlots. Smith and Miner (9) have described water pollution problems in Kansas resulting from such large feedlot operations. Hart (10) has described a manure stockpile 50 feet high, four acres in area, and containing some 400,000 cubic yards of manure which is located only 18 miles from City Hall, Los Angeles, California. This stockpile was created for manure storage, from which manure is sold at less than the cost of hauling and stockpiling, as the least expensive method of disposal. It is likely that such operations will develop in Missouri and, under the circumstances described, will represent another type of industrial waste requiring adequate treatment to prevent water pollution.

Many Missouri cities are attemping to attract new industry, and militant local groups have been organized for this purpose. Difficulty is encountered occasionally when the municipality offers to provide treatment of the industrial wastes in the municipal wastes. An oversight along these lines recently saddled a community of 3,500 population with an industrial waste having a population equivalent of about 30,000. The controversy remains unsettled at this time.

Over 200 miles of Missouri streams are affected adversely by periodic slug flows of acid waters from strip mining areas adjacent to the streams. Cedar Creek, located only ten or so miles to the east of Columbia, is almost a classic example of this problem. An encouraging note was to be found in the formation of a citizens' committee, composed of those persons holding title or residing on land adjacent to the creek, for the purpose of instituting remedial measures. Presumably a partial solution to the problem on Cedar Creek will be provided in the near future.

The University of Missouri, through the Engineering Experiment Station, is engaged in an active research program supporting the Water Pollution Board. Projects currently underway of greatest interest to those attending the Water Forum are the ones relating to sewage lagoons. Topics under investigation include a study of degradation mechanisms in the lagoon, the ability of lagoons to assimilate inorganics such as those from plating industry, and a preliminary assessment of the effects of lagoon effluents on livestock. Six faculty members from three different departments, six graduate students, and several hourly employees are involved in this research during the current year.

By way of summary on the status of municipal and industrial wastes treatment in Missouri, it may be stated that a great deal has been accomplished in the past few years. Unfortunately, even more remains to be done. As more complex problems are faced, the less certain are the correct solutions, and it appears that research will play an increasingly vital role in water pollution control. Missouri cannot afford to delay much longer the establishment of water quality criteria objectives for its streams. Such objectives are prerequisite to the most effective performance on the part of regulatory agencies. Stream surveys are in progress, but such efforts should be accelerated to provide the necessary data for prescribing water quality criteria objectives. It is important that pollution arising from sources other than municipalities and industries be given appropriate attention. Increased budgets and staffs should be provided for regulatory agencies.

Water is one of the prime assets of Missouri, and if prompt, vigorous action is not taken soon, there is a distinct probability that uncontrolled pollution will restrict sharply the optimum utilization of this water in the future.

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Nitrates and Human Health

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In the balance of information in regard to nitrates and human health, when one weighs the information known against that still unknown, I would suspect that there is a good deal more unknown which is very much in need of future research.

We are aware, for example, that nitrate salts are usually rapidly absorbed by the stomach and upper intestinal tract and then rather quickly eliminated through the kidneys. There is a suspicion from work in animals, however, which has not been documented in the human that the presence of high nitrate levels may interfere with or alter the metabolism of other substances such as iodine and vitamin A. Neither acute nor any long term toxic effects of nitr*ates* have thus far been identified or documented in the human.

One cannot speak of nitr*ates* without at the same time considering their reduced form of nitr*ites*. We know as has already been indicated in this meeting that bacterial action will reduce the nitrate to the nitrite form under certain conditions. This may happen in the soil, in the water, or in the human intestine. There *is* a good deal of information on the acute toxicity of nitr*ite*. You have probably all read the story of the Eleven Blue Men by Burton Rouche in one of our popular pocket books; in this case the poisoning resulted from accidentally adding sodium nitrite rather than ordinary table salt to the oatmeal that was prepared for the men who became ill and very blue in color.

Other cases of acute poisoning with nitr*ites* have been reported in infants as well as adults when large doses were taken by mistake. The major effect is the conversion of normal hemoglobin in the blood to methemoglobin which is incapable of carrying oxygen. When approximately 10 percent of this hemoglobin has been changed to methemoglobin the individual becomes noticeably blue and if more than 20 percent is changed to this form the individual is in severe difficulty and may die.

In the present problem in regard to water we are interested, however, not in the acute toxicity of large doses of nitrite but rather in the long term relatively low dose which may be found in some waters. There are here again no definite effects upon *adult* health which have been documented at the present time, other than the animal comparisons made in regard to thyroid or vitimin A deficiency effects.

It is in the infant that greatest concern has been felt and the major problem exists. Whether the infant drinks water containing nitr*ate* or nitr*ite*, some infants seem to be able through bacterial action in the upper intestinal tract to change the nitrate to nitrite and this is then absorbed and causes the blue-gray color due to the change in the baby's hemoglobin. This occurs quite commonly when the nitrate level in the water exceeds 10 parts per million as nitrate nitrogen.

Unfortunately this has not been a reportable disease so that when one is asked how frequently poisoning of infants occurs due to the use of nitrate-containing water, it can only be approximated by referring to the medical literature and adding up the number of cases which have been described. This was done in 1962 by Dr. Sattelmacher in Germany and the total reported (world-wide) cases were something over 1,000 with 83 deaths resulting. These cases were almost entirely found in infants under the age of 6 months. Here is a slide showing the distribution of these cases on a world-wide basis. The next slide brings this somewhat closer to home and is taken again from his World Nitrate Water Survey between 1945 and 1960, showing the number of cases and the reported deaths in this country by state. To bring home the inadequacy of these data you see here that in Missouri only three cases and no deaths were reported prior to that period. As one checks through the hospital records in any large hospital one becomes aware of many times that number. A major problem then is the recognition and the development of some reporting system in order to obtain meaningful data on how common this apparently increasing problem is becoming.

In summary, we can now say quite definitely that no infant under the age of 1 year should receive either formula or water containing more than 10 parts per million of nitrate nitrogen. The intake of such water will produce at the very least an increasing degree of blueness and if continued may well result in a fatal outcome. There is no similar knowledge in regard to the effect of nitr*ates* or nitr*ites* in low dosage over prolonged period upon adult health but the information accumulating in regard to other animal species would indicate that such information needs to be sought by further research.

Nitrate Problems as Related to Animal Health

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There is no doubt that excessive nitr*ite*, usually from nitr*ate*. may be harmful for farm animals of all kinds, as well as for man.

Dr. Marienfeld, as well as others, has mentioned the possible effects of nitrate (and nitrite) upon human beings, especially very young infants.

Rural families and their livestock are the most likely to suffer from excessive amounts of nitrate in the domestic water supplies. Some of the reasons for this have already been mentioned by Dr. Smith, Dr. Marienfeld, and others so nothing more will be said except to support what has already been said, and to emphasize the fact that we see numerous examples of interference with normal health due in whole or part to excessive nitrate (or nitrite) in the ration, water supply, or both.

Veterinarians have been familiar with acute nitrite intoxications (from nitrate, usually) for many decades. The ruminants are the usual animal affected, especially cattle. The usual source has been either direct exposure to large amounts of nitrate or nitrite compounds or from eating forages which contained high levels of nitrate or nitrite. Careless storage or use of fertilizer, dynamite, or similar substances has often led to dramatic and heavy loss of livestock, especially cattle. The dangerous properties of the drouth-stricken forages growing on highly improved soils have also been recognized for many decades but more recent reports have shed more light on the exact nature of such forages grown under drouth or other unfavorable climatic conditions.

There are many reports in the literature concerning the toxic reactions resulting from the use of nitrate or nitrite compounds in medicines, meat preservation, or as by-products in the manufacture of such products as cheese and sugar.

The rather recent recognition of an interference phenomenon which appears to be due to excessive nitrate (and or nitrite) in the water, ration, or both is less well known.

Many aspects of the possible interference syndromes caused by too much nitrate or nitrite are not well appreciated by those who make a living by raising such animals as cattle, swine, sheep, horses, and various smaller animals such as dogs, rabbits, and poultry.

Missouri workers have worked much with this problem and have reported on several different phases of the complex. Their recommendations are still among the best for recognition and correction of such problems, if modified to fit the time and place under field conditions. Several staff colleagues are actively working with problems caused by too much nitrate (or nitrite) in the ration or water supply, or both. The problem is in no way a simple one and additional aspects of it appear from time to time. One has to work away on the problem in any way that is practical under the presenting conditions.

It is likely that much of the trouble recently recognized as being an interference due to nitrate (hence, perhaps, nitrite) in the water and forage was formerly blamed on infectious diseases such as brucellosis and leptospirosis, or other conditions which have been mostly eradicated or otherwise brought under control. The interference syndrome is still recognized, in many instances, only after the other conditions that can cause a similar effect on the animals have been ruled out.

This presents a very difficult task under the prevailing conditions in Missouri. It is the job for an experienced veterinarian who is able to call on such specialists as the County Extension Director, the University of Missouri staff personnel who can often help with such problems, and in some instances, other facilities such as the A.R.S. Diseases Laboratory at Ames, Ia., or the fine commercial laboratories in the larger cities.

From our experience with this problem as clinicians with the School of Veterinary Medicine (Veterinary Clinics), correspondence with many veterinarians and owners of Missouri and adjacent states, it appears that the problem associated with excessive amounts of nitrate and nitrite in the domestic water supplies is of very wide occurrence in the "corn belt" area. Dr. George Smith mentioned many of the reasons for such contaminated water sources so there is not much point in repeating what he said except to say that our experience has been much the same, and almost always with a well or pond (sometimes a stream) which had been tied into a livestock problem in one way or another, and we seldom hear of those high-nitrate wells if there is no trouble associated with the use of them.

We have noticed, and the Canadian workers have published on it, that where nitrate (or nitrite) is present in the water supply, the amounts of nitrate (and other non-protein nitrogens) that can be tolerated in the feed ration are much less than if the water is free of both nitrate and nitrite.

It would pay most owners, if they have not already done so, to obtain a quantitative water analysis on their water supplies. This should include test for nitrate and nitrite as well as bacteria. The knowledge gained far outweighs any expense associated with the analysis, and in some areas, it would be almost impossible to calculate a balanced ration for any kind of animals without this vital knowledge.

If the nitrate interference is not too severe, one can attempt to off-set it by greatly increasing the quality of the ration, especially the energy, fat soluble vitamins, iodized salt, and better quality protein. With dangerously high levels of nitrate (or nitrite) in the water supply, the best recommendation is to change to a water supply that is free of nitrate, because of the danger of actual intoxication rather than interference with nutrition.

It is almost impossible to state with any assurance just how much nitrate can be tolerated under any given condition. Recommendations are made low enough to allow for unusual sensitivity as well as what may be considered average conditions. The individual animal tolerance is so varied that one has to make recommendations far under those usually expected to cause trouble. The amount to make an animal sick or to cause death is not the best guide to use when trying to correct or eliminate the interference syndromes which may be due to nitrate or nitrite in the water supply. All other sources of nitrate and nitrite must be considered when attempting to evaluate the significance of any given amount of nitrate in the water supply. To do otherwise is to reckon with the unknown.

Nitrate Problems in Water as Related to Soils, Plants and Water

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Since the drouth years of 1953-54, toxic levels of nitrates in forages have frequently been suspected when the cause of livestock troubles was not obvious. In many cases where nitrates have contributed to problems in livestock production, water, in addition to feed, has been found to be a source of this ion.

The use of chemical nitrogen fertilizers has increased rapidly during the past two decades—and is still growing. This soil amendment now accounts for more than 30 percent of our agricultural production.

Nitrogen is essential for plant growth and most is absorbed from the soil as nitrate. In some plants the nitrates are reduced to protein in the roots while in other species this transformation takes place in the leaves. Tissue tests for nitrate content are regularly used by agronomists to determine if the rate of soil treatment has been adequate. High nitrate content of some forages and vegetables may be found after improper or excessive nitrogen fertilization or when drouth, cloudy weather, or some other adverse growth condition prevents the plant enzyme system from converting the nitrate nitrogen to protein. Little nitrate has been found in grains.

Contamination of rural water supplies with nitrate (or nitrite) has been found to be associated with leachates from feedlots, which have been established as a main source in many contaminated aquifers. Fertilizer nitrogen has been of little importance in water contamination.

There have been many inconsistencies in the associations between nitrogen fertilizer use and animal health. For example, nitrate toxicity from forages has been blamed for losses in milk or meat production where little chemical fertilizer has been applied. The quantity of nitrate or nitrite recently found in many water supplies is too large (particularly in the Missouri Ozark Region) to be explained by contamination from chemical fertilizers.

*Research information in this report was obtained in part from U. S. Public Health Service grants EF 00467 and WP 00533.

Many Water Supplies Contain Nitrate

Analyses of nearly 5,000 water samples for nitrate and nitrite in 45 counties in Missouri during the past year show that about 42 percent contained over 5 ppm of nitrate-nitrogen, a concentration high enough to be considered important in livestock production and in infant feeding (Fig. 1). Nitrate-nitrogen in these water samples varied from a low of 12 percent to over 75 percent in individual counties. Highest contamination was found in areas with the largest livestock production. There was good correlation between the nitrate content in well water and hydrologic geologic areas, but only a limited relationship with soil types. The greatest number of water supplies with high nitrate (and nitrite) were in the northern part of the state where pervious loess overlies low-permeability glacial clays, and where the water accumulates at the junction of these two materials (see Fig. 2). In this region water from artesian and deeply buried aquifers is too saline for domestic use, necessitating that most rural water supplies be taken from aquifers 15 to 50 feet deep (in glacial valleys or at perched water tables). This area has been farmed for 75 to 150 years and livestock production is the main source of income. Many of the farm water supplies are located close to feedlots or silos. There is a high degree of correlation (see Fig. 3) between the occurrence and concentration of nitrate in these wells and their proximity to livestock feeding areas.

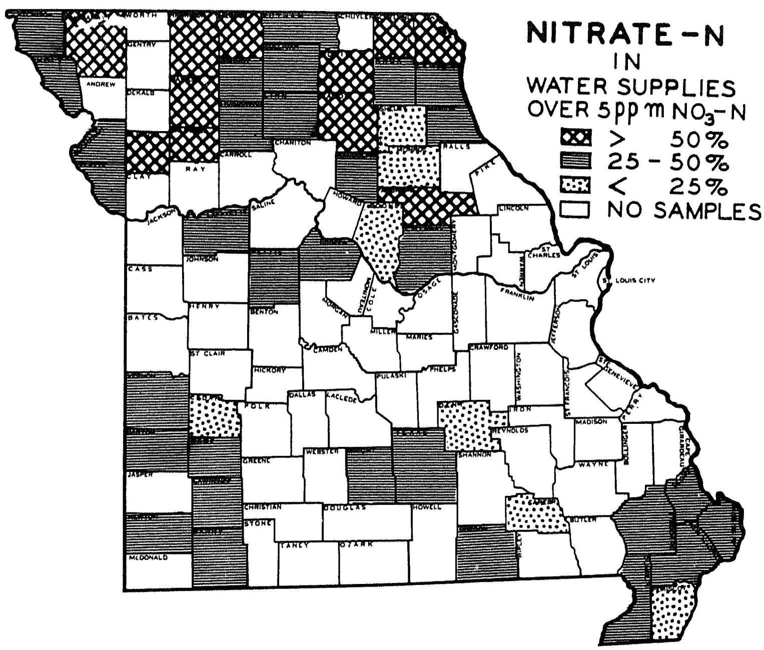


Fig. 1—Counties in Missouri Where Over 5000 Water Supplies Have Been Analyzed for Nitrates. Counties Were Selected on the Basis of Geologic and Soil Regions.

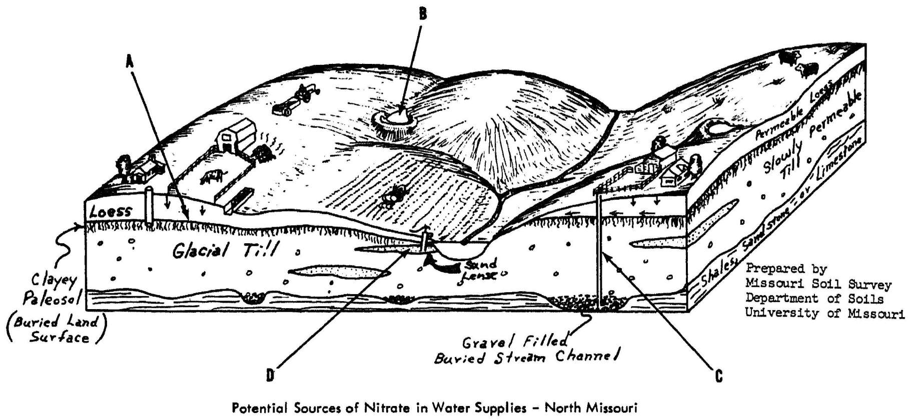


Fig. 2—(A) Drainage from feedlot, leaches through pervious loess strata and moves laterally above clay layers to shallow wells. (Note that well is on high ground above feedlot.) (B) Few ponds have been found to contain nitrates. (C) Some of the best wells of northwest Missouri are those that tap the water from old glacial valleys. Deeper wells may have a high salt content. (D) No evidence has been found that fertilizer nitrogen in an important source of nitrate in water.

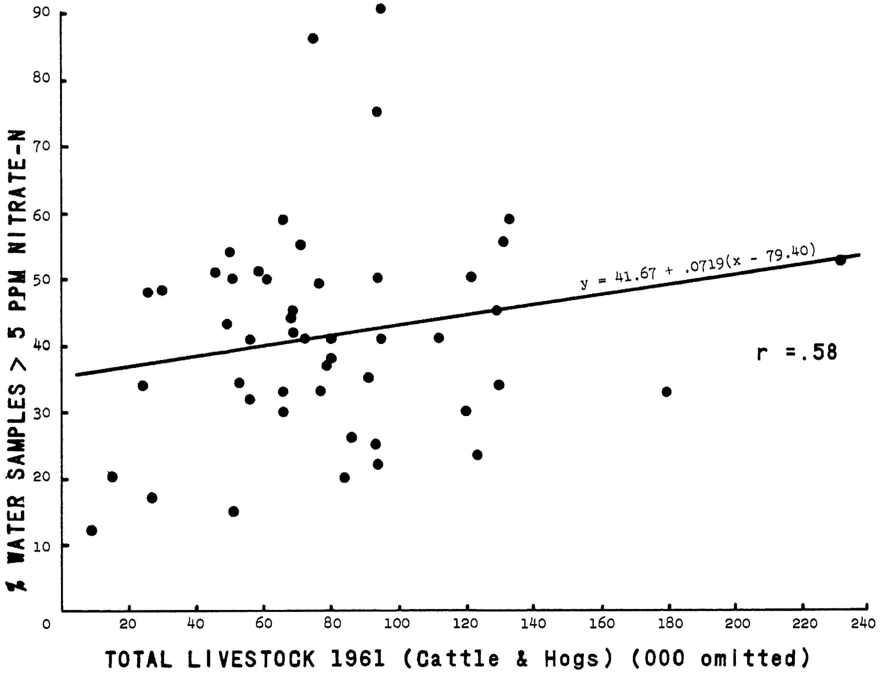


Fig. 3—Relationship Between the Number of Livestock in Individual Counties in Missouri and the Percentage of Wells Containing More Than 5 PPM of Nitrate-Nitrogen.

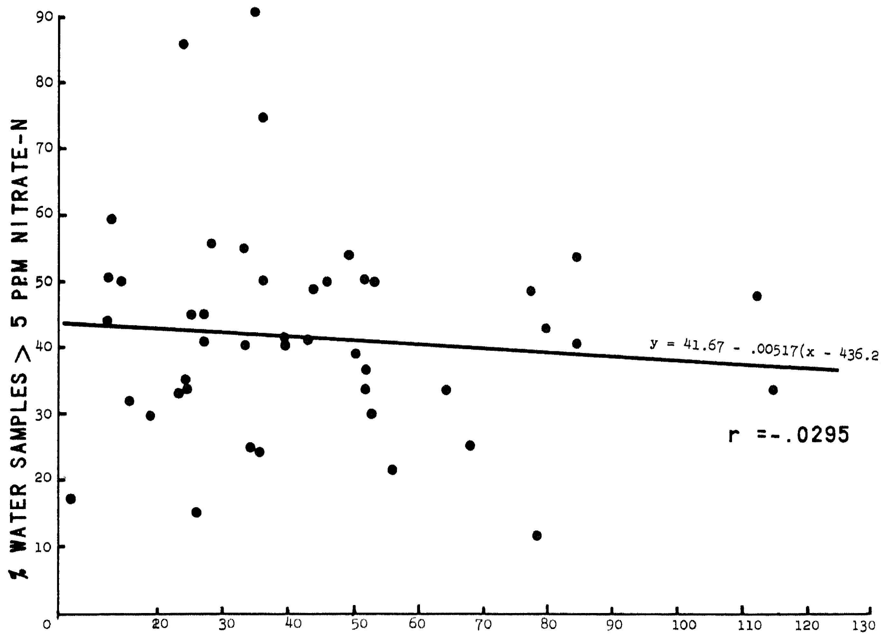


Fig. 4—This diagram shows the lack of correlation between the amount of nitrogen fertilizer used in individual Missouri counties and the percentage of wells containing over 5 PPM of nitrate-nitrogen.

There was no correlation between the number of water supplies containing nitrate and the use of nitrogen fertilizers on a county basis (see Fig. 4). This correlation included all of the water sampled regardless of source in 45 counties. The nitrogen fertilizer use was taken from county figures reported under the Missouri Fertilizer Law.

Soils Under Feedlots Contain Nitrates

Soils in feedlots in the loess-glacial areas have been sampled to depths of 10 to 20 feet and determinations made for nitrates and bacterial numbers in the different horizons. The analyses for nitrates and bacterial contents of soil under feedlots in Clinton and Macon counties are given in Fig. 5, and are typical of results obtained on a large number of soils in the northern part of the state.

In a depth of 14 feet (Clinton County soil) a total of 2022 pounds of nitrate-nitrogen per acre was found. Over 1700 pounds of the nitrogen was below 52 inches.

The soil samples from Macon County were taken to a depth of 23 feet, and contained over 4600 pounds of nitrogen as nitrate. The soil at the Clinton County site contained over 300 pounds of nitrogen per acre foot at the 6-foot

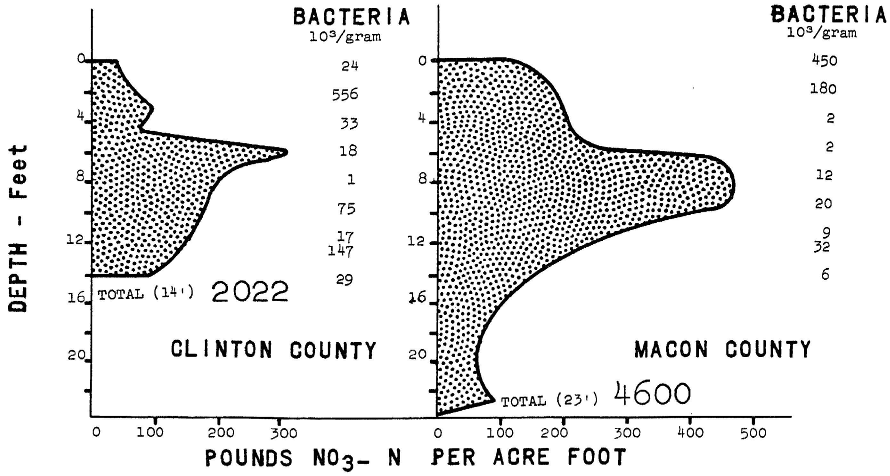


Fig. 5—Nitrate nitrogen and bacterial content of soil at different depths under old livestock feeding areas.

depth and over 400 pounds in the 8-10 foot depth in Macon County. The amount of nitrate-nitrogen in the Macon County sample is of particular interest since no livestock has been in this area for a number of years (buildings and fences have been removed), and there was a vigorous growth of vegetation over the surrounding area. No chemical fertilizer has been used within 400 yards of the well. A pond on the farm that received drainage from a heavily fertilized cornfield in 1964 gave a negative qualitative test for nitrates when samples were collected a number of times the past year.

Bacterial numbers were low in soils from both locations. In many soils there is little energy material in these lower soil horizons. From the high nitrate content still found in a number of deep soil samples where livestock has been fed for years, but none have been around for five to ten years, it appears that once nitrate moves to more than five feet below the surface it is preserved.

Evidence has also been obtained that when some energy material is present in the deeper soil horizons anaerobic organisms may change some nitrate to nitrite. This could explain the positive tests for nitrites that have been obtained in some wells. Some indication has been obtained that nitrogen from buried soils or nitrogen-containing shales may also contribute nitrate to some aquifers. However, this type of reaction does not fit present concepts of soil chemistry, and has not been verified.

Deep Wells in Limestone-Solution Areas Contain Nitrate

Preliminary tabulation of results of water samples taken in Cooper County show a high percentage of deep-drilled wells (many over 300 feet deep), containing significant amounts of nitrate. This soil is loessial in origin and from 5 to 50 feet deep. It covers weathered limestone at varied depths.

There are caves in the area and some farms contain numerous sink holes. The soil is productive and there is extensive cattle feeding and hog production. The entire county used about 2000 tons of nitrogen in commercial fertilizers during 1963. This was about 28 pounds of nitrogen per harvested crop acre. Table 1 gives a summary of 371 samples of water supplies sampled during the spring of 1964. These results show that nearly 50 percent of the drilled wells, 65 percent of the cisterns, over 85 percent of the dug wells and over 80 percent of the springs contained over 5 ppm of nitrogen as NO_3.

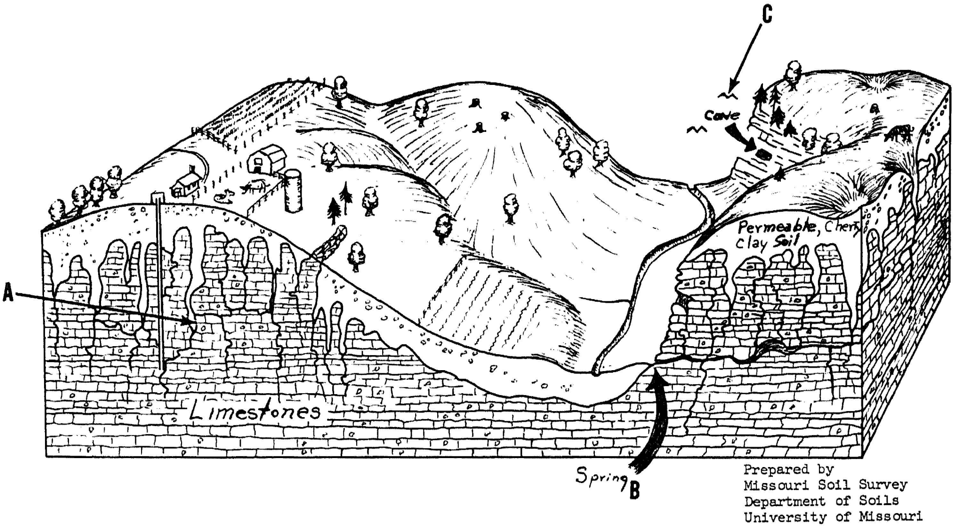
Table 1. Nitrates in Water Supplies-Cooper County, Missouri (Spring 1964)

Type	Number Sampled	Number > 5 ppm NO_3-N
Drilled	255	126
Cisterns	28	18
Dug	31	27
Spring	37	31
Ponds	15	2
Driven	3	3
Artesian	2	0
Total	371	207 (55 percent)

Much of the soil in the area in Missouri south of the Missouri River was derived from the weathering of cherty dolomite Ca-$MgCO_3$ and limestone, Ca-CO_3. Many soils contain numerous stones and have a high infiltration rate. The underlying carbonate rocks show highly fractured and irregularly weathered upper surfaces. Usually wells in this area are cased only a few feet into the partially weathered stone.

The southern portion of the state does not have as many wells containing nitrate, nor concentrations as high, as are found in the glaciated areas of northern Missouri. There is only a relatively small number of livestock in many areas of south Missouri, and the amount of chemical nitrogen fertilizer used is much smaller than in other areas of the state. However, numerous drilled wells from 100 to 300 feet deep contain enough nitrate to be of concern in dairy farming. Usually these wells are located in a feedlot at a high point on the farm. Surface conditions around the immediate well site prevent surface water from entering the casings at the surface, but where animals have been fed and housed in the area for years the water may contain nitrate.

It is believed that in this area of pervious soils, cavernous limestone, and inadequately cased wells, the leachings from manure at the surface may be carried into these underground water sources. This region is replete with caves, underground drainage, large springs and sink holes (see Fig. 6). A number of specific cases have been found where chemical nitrogen fertilizers have been cited as



Potential Sources of Nitrate in Water Supplies - South Missouri.

Fig. 6—(A) The well on top of ridge could be contaminated by infiltration from feedlots and silo drainage. (B) Nitrate in spring water can originate from manure and organic wastes entering underground water through sink holes, or (C) from bat guano deposits in caves.

the cause for high nitrate content found anomalously in deep drilled wells; but also it has been recognized that in the immediate area are "sink holes" where livestock are fed or where untreated sewage empties into these underground fissures and caverns. No cases have been found in this large area of gravelly soils where nitrate in well water can be traced to chemical nitrogen fertilizer applied to crops or to contamination from fertilizer storage.

Nitrate Content of Well Water Fluctuates

Samples of water collected at monthly intervals over a period of two years in Cooper County from wells that ranged from 40 to 463 feet deep showed wide fluctuation in nitrate content that could not be correlated with rainfall (Table 2). Tests for nitrate have also been made on a number of wells after different periods of pumping. Some wells have shown a reduced nitrate content with pumping, while the water in others will increase in nitrate concentration. It is the opinion of the author that where an aquifer is limited in size heavy pumping or infiltration of rainfall will cause a reduction of nitrate concentration. However, where the contamination area is extensive, or where the soil above an aquifer has a high nitrate content, movement of water from the surface from displacement by pumping or rainfall infiltration will result in a higher concentration of nitrate. It is further believed that these changes in nitrate content of water with season will be influenced by the geologic formations and the amount of nitrate in the deep layers of soil above the aquifers.

Table 2. Nitrate-Nitrogen and Chloride Content of Well Water at Monthly Intervals Over a Two-Year Period (July 1962-July 1964), Cooper County, Missouri. (Adopted from Fuller: Missouri Geological Survey)

Farm	Well Depth (feet)	Farming system	Fertilizer Manure**	Surface water***	Barnyard or silo near	Range-ppm Cl^-	Range-ppm NO_3^--N
A	160	General	Low	Yes	Yes	17- 52	5- 41
B	190	Crops	Low	No	Yes	33- 46	34-100
C	300	General	Low	No	No	38- 43	13- 22
D	305	General	None	Yes	Yes	61- 65	24- 55
E	463	Beef	Low	Yes	Yes	1- 12	0- 6
F	91	General	None	No	No	205-413	0- 3
G	40*	Beef-Hogs	Low	Yes	Yes	23-131	1-16
H	160	General	Low	Yes	Yes	71-100	22-38
I	200	General	Low	No	Yes	113-145	6-40
J	473	General	Low	No	Yes	3-17	1-4
K	180	General	Low	No	Yes	39-54	9-12

*Dug well - remainder drilled

**Use within one-fourth mile of well

***Surface water can stand in vicinty of well - not run into casing.

Spring Water Contains Nitrates

The residual limestone area of south Missouri is largely in forest and unimproved pasture, and little chemical nitrogen fertilizer is used. Many large springs, caves and sink holes are found in this area. A nitrate nitrogen content of 5 to 15 ppm in the spring water could be accounted for by natural soil leachates and/or bat guano in the caves.

For example, Big Spring in Shannon County has a maximum flow of over 800 million gallons of water daily. An average daily flow of 252 million gallons has been found over a 17-year period. Analyses of the water in 1964 showed an NO_3-N content of 2.4 to 3.0 ppm. Three ppm in 252 million gallons of water is over 6000 pounds of nitrogen. The drainage area of Big Spring has been estimated as 440 square miles. Assuming that one-fourth of the 48 inches of annual rainfall percolates through the soil, and average of 250 million gallons daily would be obtained. A discharge of 6000 pounds of nitrogen daily would amount to less than 8 pounds of nitrogen per acre per year, a realistic leaching loss even on the low fertility forest soils of the area. Five or more pounds of nitrogen per acre is added to soils in precipitation each year. This regular addition of nitrogen in rainfall could account for most of the nitrate discharged by this spring. It is also of interest that the use of nitrogen fertilizer in the drainage area of this large spring in 1963 was only about 65 percent of the nitrate discharged in the flow of this single spring.

Many caves in Missouri (and in other parts of the United States) have been used in the past as sources of potassium nitrate for the manufacture of gunpowder. This caliche was secured as crystalline KNO_3 from wall and crevices (probably infiltrates and from leaching from bat guano deposits). About one-third of the known caves in Missouri have been reported to contain bat guano. Good correlations have been obtained for nitrate in spring water flowing from caves and guano deposits. Watercress in water courses is an indicator of nitrates in water in south Missouri. Watercress has been analyzed and contained from .25 to .96 percent nitrate-nitrogen (dry weight basis). Watercress has not been found in spring water discharge that does not contain nitrate at some season of the year.

Because of the highly fissured and cavernous nature of the soluble limestone-dolomite rocks in the Ozark Region, it is plausible that leachates from bat guano deposits could descend to deep aquifers and provide a high nitrate content in water from strata reached by deep wells. Fig. 6 illustrates the conditions that are believed to be responsible for nitrate contamination of water in extensive areas of south Missouri.

Surface Reservoirs Usually Free of Nitrates

Analyses of numerous samples of pond water have shown very low concentrations of nitrate—even when receiving drainage from feeding areas or pastures. This is to be expected since aquatic plants which require nitrogen for growth, remove NO_3 ions as soon as they reach the impoundments after runoff. In only a few cases have significant amounts of nitrates from fertilized fields been found in ponds after heavy runoff. Measurements of nitrate in the runoff water in experiments at the Midwest Claypan Experiment Station during 1963 and 1964 showed less than .1 pound of NO_3-N per acre where 100 pounds of N as ammonium nitrate were applied to the soil.

Nitrites in Water Supplies

Some water supplies have shown from 2 to 10 ppm of nitrite-nitrogen. (Nitrite is considered at least ten times as toxic to livestock as nitrate.) The reason for nitrite being present in water at some seasons is not understood. A greater number of wells containing nitrite were found during the hot summer months than during the fall and winter. However, it is possible that at high temperatures (70°-90°F.) plant growth may cause a deficiency of O_2 and anaerobic organisms may reduce NO_3 to NO_2. It is also possible where water stands in zinc-lined pipes or tanks at these higher temperatures that a chemical reduction of NO_3 to NO_2 may take place. The possibility of this reaction is being investigated.

Young Plants Highest in Nitrates

Nitrates are highest in liberally-fertilized young plants. Where crops are grown under a well-balanced nutrient media and normal environment, the nitrate-nitrogen is rapidly metabolized into proteins as the plants mature. In many forage species only traces of nitrate can be found at the bloom stage. Cereal grains do not show nitrates. There are some analyses of oil seed meals that have contained significant quantities of this ion. Most livestock problems with nitrates develop from the feeding of silage—particularly where land has been excessively manured or fertilized and when drouths occur. Alfalfa hay (no fertilization) grown under dry land conditions frequently contains sufficient nitrate to contribute to the over-all animal intake and cause problems—particularly if the water or other forage in the ration contains nitrate.

Heavy Manuring Causes Troubles With Silage in Dry Seasons

The source of nitrogen, whether legume nitrogen, nitrogen from the mineralization of soil organic matter, or from farm manures, makes little difference in the accumulation of nitrate by corn or other crops used for silage. Nitrates can be present in toxic amounts in corn silage where the nitrogen available to the crop is excessive, or where some mineral nutrient is deficient, or where drouth or high temperatures prevent the formation of grain. Seldom is a significant amount of nitrate found in corn if the yield is over 75 bushels per acre. However, when sufficient nitrogen is available in the soil to produce 100 bushels, but when the weather limits yields to 40 bushels or less, the nitrate remains in the vegetative portion without being reduced to the amino form.

The highest nitrate levels found in corn and sudan have been in crops grown on heavily manured land or where feedlot areas have been planted. Frequently the amount of nitrogen applied in heavy manuring is much greater per acre than is ever applied as chemical nitrogen fertilizers.

Since manures are usually low in phosphorus, plants produced on heavily manured land may be growing under an improper mineral balance. A low level of phosphorus, potassium or some other element can cause an accumulation of nitrate. The nitrate content of forages can be reduced where deficiencies of phosphorus, potassium or calcium are corrected. The results of the analyses of Smart weeds (P. Pennsylvanicum) collected from vegetable plots, are of practical interest in the harvesting of silage crops. Studies have shown that a number of weed species are nitrate accumulators. Setting the silage cutter high to leave this weed vegetation in the field will reduce the nitrate content of the silage.

Conclusions

A large percentage of rural wells in Missouri contain sufficient nitrate to be a factor in the health of livestock. Leachates from long-time feeding areas on permeable soil where the aquifer occurs at the junction with glacial clays appear to be a main source of concentration. In areas where soils are underlain by fissured or solution cavities in limestone, significant amounts of nitrate have penetrated to depths of over 200 feet. Leachates from guano deposits or the mineralization of soil organic matter have also been established as contributing to nitrate in water supplies in some areas. Both rural and city water supplies have been found where sewage was responsible for both nitrate and nitrite in water.

Little evidence has been found that chemical nitrogen fertilizers are responsible for nitrates in water supplies. Nitrate accumulation can occur in many plants which under normal growth and balanced nutrition contain only trace amounts of nitrate. However, when excess nitrogen is available within the soil, when deficiencies or excesses of other plant nutrients occur during active plant growth, or when abnormal environmental conditions retard plant development, nitrates can accumulate.

The continued use of excess nitrogen in fertilizers could become an important factor in maintaining pure water in the shallow aquifers. This possibility should be of concern to the suppliers and users of nitrogen as well as those responsible for supplying the public with quality drinking water. Since nitrogen fertilizers will be used in increasing amounts to supply adequate nutritious food for a growing population, it is essential to understand basic soil chemistry and plant nutrition. This will permit quality crops to be produced, without excesses of applied nitrogen, that will accumulate in plants or could eventually accumulate and contaminate drinking water. Data accumulated on this study during the past year indicate the following:

Nitrate-Nitrite Contamination in Water

...In rural areas, infiltrates from feedlots are the main source of nitrate in water supplies.

...Septic tank effluent in some soils and nitrification of guano in limestone solution regions contribute to the nitrate in some water supplies.

...Animal manures, mineralization of nitrogen from soil and crop residues, and the nitrogen in precipitation add to the nitrate entering underground water.

. .Geologic formations are more influential on the amount of nitrates in underground water than are the properties of individual soils.

...Nitrogen fertilizers are not important now but can eventually be a contaminant in water.

Plant-Accumulation of Nitrates

...Heavy manure treatments supply excess nitrogen, but insufficient levels of phosphorus.

...Plant species and strains vary in capacity to change nitrate to protein nitrogen.

...There is little nitrate in grain. Most is in vegetative portions.

...Adequate levels (not excesses) of all essential plant nutrients are required for normal nitrate content.

...Highest nitrates are found in dry, hot seasons.

...Unfertilized legume crops frequently have high nitrate content.

...With optimum nitrogen fertilization and normal growing conditions, nitrates are not a problem in plants.