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River Quality Assessment: Implications of a Prototype Project

Results of the Willamette River, Oregon, have national implications for resource management programs.

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There is an urgent need for comprehensive resource assessment in most river basins of the United States (*1*). In response to this need, many planning groups have prepared reports that project future demands for water supply, waste-water treatment, and other services and have suggested possible alternatives for meeting the demands. Implicit in these reports is the acceptance of economic and population growth, but it is assumed that such growth will proceed in a manner consistent with some desired level of land and river quality.

Virtually all forms of economic growth and land development exert some impact on river quality. Achievement of desirable river quality at acceptable cost requires that management decisions be based on sound impact assessments, not on arbitrary assumptions. Thus, the vital link between resource-development plans and management decisions is scientific assessment to predict the probable impacts of each planning alternative. At present, the impact-assessment link is a stumbling block to the overall process (*2*). The difficulty in appraising impacts results from (i) absence of a rational framework for structuring such work; (ii) absence of well-developed, ready-to-use assessment methods; and (iii) scarcity of reliable data.

Summary. The U.S. Geological Survey recently completed an intensive river quality assessment study of the Willamette River basin, Oregon. The most noteworthy finding was that across-the-board advanced waste treatment was not the answer to the problem of meeting stringent water quality standards established for the Willamette River. This implies that rigid nationwide standards and regulations are likely to result in unneeded expenditures in some river basins and in unachieved standards in others. It was also found that existing water quality data collected under monitoring- and surveillance-type programs are inadequate for defining the critical cause-effect relationships that control river quality problems. Intensive, synoptic surveys keyed to local problems and conditions are required to provide an adequate information base for making key management decisions.

Several years ago, the three noted deficiencies were formally recognized by the Department of the Interior's Advisory Committee on Water Data for Public Use. In 1972, the committee recommended that the U.S. Geological Survey help remedy the deficiencies by conducting a pilot, interdisciplinary river quality study. The recommended objectives were to (i) define a practical framework for conducting comprehensive river quality assessments; (ii) determine the kinds and amounts of data required to adequately assess various types of river quality problems; (iii) develop techniques for evaluating and reporting such data so as to promote better public understanding of their significance; (iv) develop and document methods for assessing planning alternatives in terms of potential impacts on river quality; and (v) apply the framework, data programs, and methods to assess the critical river quality problems of a major river basin.

In January 1973, the Geological Survey started a prototype river quality assessment study of the Willamette River basin, Oregon (Fig. 1). The Willamette River basin was selected for several reasons. First, there was an excellent base of background data, particularly on hydrology. Second, social and political attitudes in Oregon reflected a keen interest in environmental quality. This interest suggested that the people and agencies would welcome the study and that results would be used at the state and local levels. Third, a river-basin management plan already existed, as did several land-use projections. Thus, the study could evaluate existing planning alternatives to provide a realistic test of assessment approaches. Fourth, the Willamette was the largest river in the nation on which all major point-source (*3*) discharges received secondary waste-water treatment. Also, during summer, riverflows were augmented by releases from a system of 11 reservoirs. Thus, by choosing the Willamette, it was possible to appraise the relative importance of waste-water treatment and flow augmentation on the quality of a major river.

The Willamette study initiated and developed the concept of river quality assessment as a means for obtaining adequate, technically sound, and timely information for resource planning and management (*4*).

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Assessment Framework

River quality problems stem basically from two factors, the natural hydrology of a river basin and the development and use of the land and water resources by human beings. Depending on the interrelation of these factors, a wide variety of quality problems can result. Each river basin, therefore, is unique, and it follows that each one must be subjected to individual and intensive river quality assessment to provide a proper basis for judicious management of the land and water resources.

In the broadest context, river quality assessment is a problem-oriented approach for developing information that is appropriate and adequate for sound resource management. In a more specific sense, river quality assessment is the science and art of identifying the significant resource problems, defining them with relevant data, and developing methods for evaluating the impacts of planning alternatives on each specific problem (5). In order to predict the consequences of any plan of action, it is essential to have a fundamental understanding of cause-effect relationships. Assessment, therefore, extends far beyond basic data on the physical, chemical, and biological quality of water to measurement of pollution sources and the prevailing hydrologic conditions that cause the observed effect. When, by scientific analysis, cause-effect relationships are defined and verified, assessment becomes a powerful, predictive method for evaluating alternative plans of action and for establishing priorities.

In keeping with this philosophy, the approach developed for the Willamette study included the seven steps that are outlined across the bottom of Fig. 2. River quality is but one of many factors that decision-makers consider in choosing among alternative plans; it is a single component of the natural resource system, which, in turn, is only one aspect of the socioeconomic-political-environmental structure of river-basin management. In many basins, demographic and economic uncertainties may be greater than the river quality uncertainties. Such a situation actually increases the need for assessment, because a sound understanding of river quality might provide a starting point for systematic evaluation of the socioeconomic and political options and of the technical alternatives for control of land and water resources development.

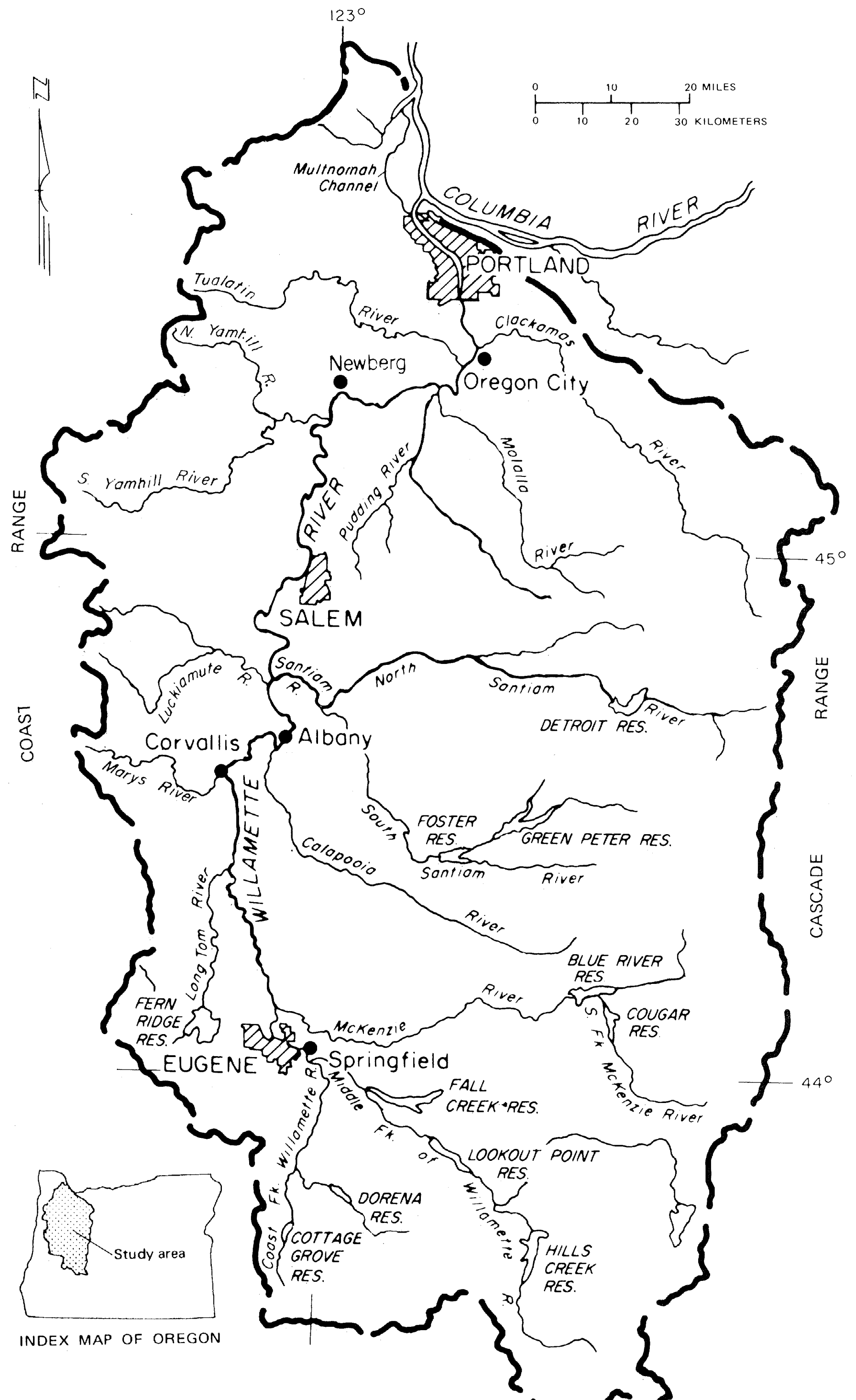

Fig. 1. A map of the Willamette River basin, Oregon, emphasizing the main stem, principal tributaries, and major reservoirs.

Program Design

In establishing a framework for the prototype assessment, the Geological Survey gave particular consideration to optimal study duration, staffing, and the specific problems to be evaluated (6). In determining the duration of the study, a compromise had to be made between conducting a long-term, research-oriented study and a short, deadline-oriented study in which unexpected problems and questionable results could not be evaluated. A study duration of 2½ years, which allowed two summer field seasons, was finally selected. This gave us enough time to check and recheck certain critical problems, and to provide data on which resource managers could base their decision-making.

Staff needs were based on an interdisciplinary team-oriented approach (7).

The selected team included scientists and engineers experienced in river work and trained in the disciplines of hydrology, chemistry, aquatic biology, mathematical modeling, and geology.

Specific work elements for the program were selected in discussions with state, interstate, and federal agencies concerned with river quality management. Eight existing or potential problems were identified (Table 1). After the problems were evaluated and ranked, four of them were selected for study: dissolved oxygen (DO) depletion, potential for algal problems, trace-metal occurrence, and the impact of land-use activity on erosion.

Table 1. Existing or potential river quality problems of the Willamette River basin, Oregon. The problems were ranked from 1 to 3 according to their relative importance, with 1 indicating greatest, and 3, least importance.

Problem	Rank	Selected for present study
Pollution from nonpoint sources	3	
Quality of water released from reservoirs	3	
Dissolved oxygen depletion	1	X
Potential for algal problems	2	X
Occurrence of trace metals	1	X
Sanitary quality	3	
Accelerated erosion	1	X
Riverbank esthetics	2	

Assessment Results

Detailed results of the assessment have been described (*8*). Here we discuss some conclusions drawn from the results to illustrate their local and national implications.

Dissolved oxygen depletion. Historically, severe DO depletion during summer has been the critical quality problem in the Willamette River (*9*). In recent years, summer DO levels have increased dramatically (Fig. 3) because all point-source wastes (*3*) have received secondary biological treatment and the streamflow has been augmented from storage reservoirs.

Although secondary treatment improved river quality, it resulted in pulp- and paper-mill effluents being discharged continuously into the river, whereas previously these effluents had been stored (in lagoons) in the summer and discharged only during winter. The advent of biological treatment also resulted in the use of ammonium hydroxide for neutralizing the raw waste waters at certain pulp and paper mills. During the summers of 1973 and 1974, the ammonia in the effluent of one mill caused a large DO depletion between river miles 86 and 50 which had not occurred previously (*10*). Reduction of ammonia loading from this one source offers a relatively simple alternative for achieving a large (as much as 20 percent) improvement in summer DO levels (*11*).

In contrast, at foreseeable levels of development, further reduction in the point-source discharge of organic wastes beyond that achieved by efficient secondary treatment would produce only limited improvement in DO concentrations. Only about half of the summertime loading of organic, oxygen-demanding wastes now comes from point sources (Table 2). The other half essentially represents natural background biochemical oxygen demand (BOD) (nonpoint sources) from sparsely developed, tributary basins. This demand cannot be removed by pollution-control programs.

Even with basinwide secondary treatment and a reasonable limitation on ammonia loading, flow augmentation will be needed to maintain the Willamette's high DO standards. As basin development continues, flow augmentation from reservoirs will continue to be necessary even as certain large dischargers upgrade their treatment to more efficient levels.

Potential for algal problems. A potential for algal problems may exist in the Willamette River because point-source discharges cause the concentrations of nitrogen and phosphorus to be high. To date, however, algal growths have not become a nuisance, and results indicate that the primary reason for maintenance of favorable algal populations in the Willamette is the short detention time of water in the river (*12*).

Perhaps the most important aspect of the short detention time is the constant nutrient influx that prevents depletion of major nutrients. The maintenance of a balance in major nutrients favors the growth of desirable rather than undesirable types of algae. Thus, in the Willamette the key to keeping algal growth at its present level appears to be control of those factors that maximize summertime flow and minimize water-detention time. Such control would require maintenance of present levels of flow augmentation and avoidance of large volumes of water being withdrawn for agricultural purposes.

The results imply that national or regional standards for permissible nitrogen and phosphorus concentrations represent a poor management tool. The need for advanced waste treatment to remove point-source nitrogen and phosphorus should be assessed on a river-by-river basis.

Trace-metal occurrence. When present in critical concentrations, many materials discharged into rivers are toxic to aquatic organisms. A review of records for the Willamette River basin showed there was little possibility that toxicity problems could result from pesticides and other organic chemicals. However, few data were available on the discharge of trace metals and their possible accumulation in sediments and food chains.

To partly fill this void, we designed a

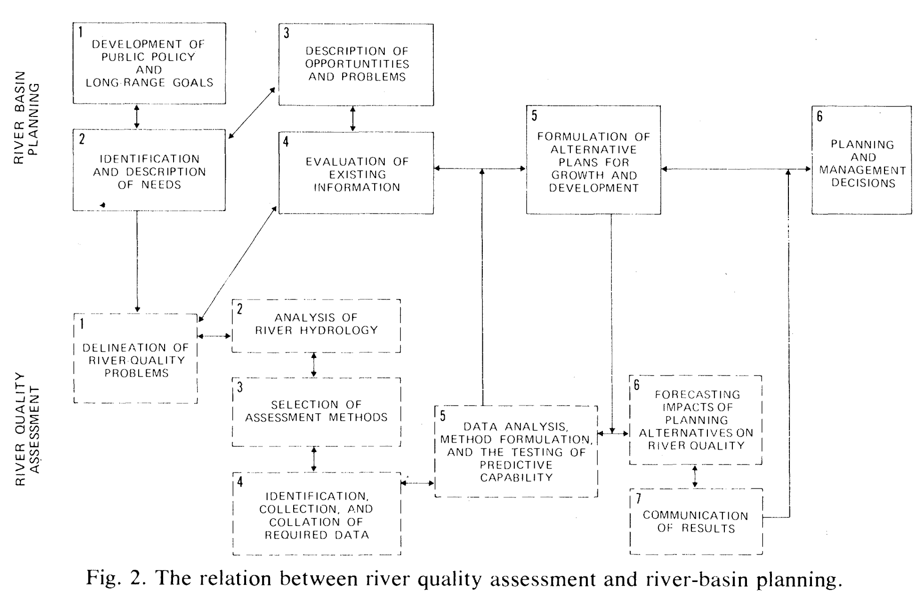

Fig. 2. The relation between river quality assessment and river-basin planning.

study to determine the concentration and distribution of selected metals in river-bottom sediments. The objectives were to establish baseline data for future comparisons and to provide an alert to possible accumulations of toxic metals. The study approach involved the sampling of bottom sediments under stable low-flow conditions, fractionation of samples to obtain fine-grained materials prior to metal analysis, and interpretation of trace-metal data through the use of probability graphs.

The results suggested that no metals were present at levels that might represent an ecological threat (*13*). There were moderate enrichments of zinc, resulting from industrial discharges, and slight enrichments of lead, resulting from urban runoff.

The procedures developed in the study are considered suitable for detecting the extent of trace-metal occurrence in almost any river.

Land use and erosion. Great increases in population and in industry over the next 50 years are predicted for the Willamette River basin. At present, the potential impacts of this development on land and water quality have not been appraised.

We made an initial assessment by devising a synoptic approach to delineate the relations between physiographic factors, land-use activities, and resultant erosional-depositional problems (*14*). The approach involved the development of a basinwide erosional-province map and a matrix for rating erosional impacts. Data on geology and slope were collated to delineate eight units of terrain having different natural potentials to erode or receive sediment. Infrared aerial photographs were used to identify land-use activities and to map existing erosional and depositional features. The matrix was formulated by placing order-of-magnitude erosional factors for geology and slope as columns and similar factors for land-use activities as rows.

Together, the map and matrix serve as tools for estimating the erosional impact of human activities on different types of terrain. The tools have already proved useful for the design of improved data-collection programs, and currently are being used as the basis for the Oregon 208 Assessment of nonpoint-source problems.

Table 2. Average daily ultimate BOD loading to the Willamette River, Oregon, during summer dry-weather conditions, 1974.

Source	Loading (kilograms of DO per day)	Percentage
Nonpoint	34,900	46
Point		
Municipal	17,100	22
Industrial	24,700	32
Total	76,700	100

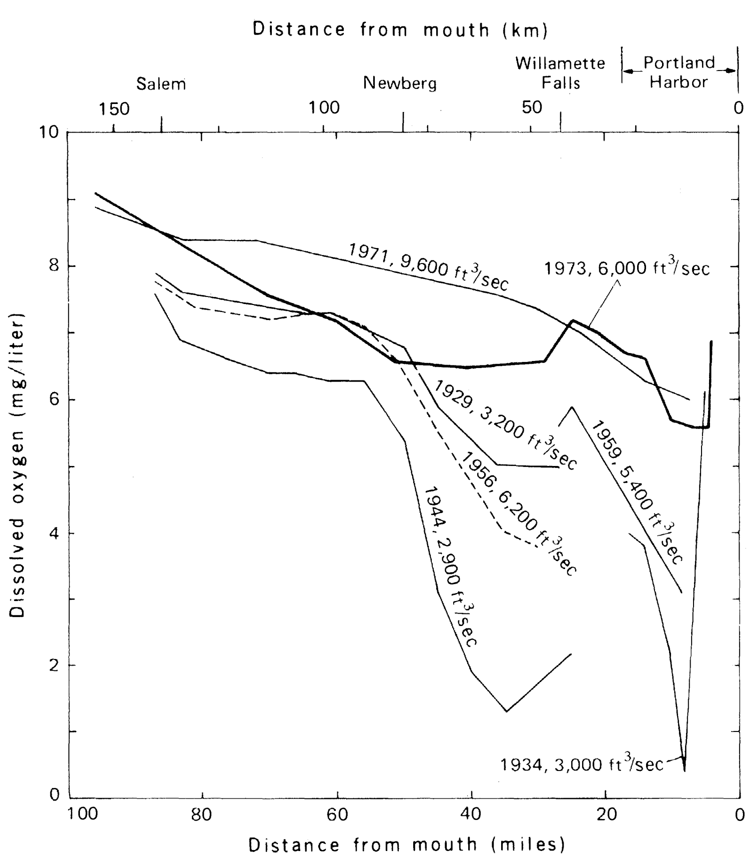

Fig. 3. A comparison of dissolved oxygen profiles for 1973 and historical dates (*9*) for the Willamette River during the summer low-flow period.

Implications for Science and Engineering

The Willamette study emphasized the development of approaches, methods, and data programs that would be useful in the assessment of other river basins. From this effort, and from the study results, certain findings emerged that are pertinent to programs of the scientific and engineering community.

Inadequacy of existing data. Except for flow records, the large data base that existed for the Willamette River was found to be unsuitable for assessment of DO depletion, potential for algal problems, and the occurrence of trace metals in the river. The unsuitability resulted primarily from the fact that existing data were collected under routine monitoring- and surveillance-type programs. Such programs are designed, not to assess specific problems, but to provide a general indication of water quality trends and to check for compliance with stream standards. Data generated for these purposes are generally inadequate for defining the critical cause-effect relationships that control most river quality problems. This was true for the Willamette, and indications are that it is true for most other rivers in the United States.

We found that short-term, intensive studies of the synoptic type were needed to provide the kinds of data required for assessing the three "in-river" problems (*15*). In contrast to monitoring- and surveillance-type programs, the synoptic approach permits the critical temporal and spatial changes in river quality caused by hydrologic factors and waste loadings to be more easily recognized, separated, and quantified.

From experience gained on the Willamette, we believe that intensive synoptic studies will be required in most river basins to develop an adequate information base for assessment and management of key river quality problems.

Role of mathematical models. Mathematical models can be used effectively for the practical assessment of certain river quality problems. However, the models must be based on sound data and reliable assumptions, with mathematics and the computer used as tools rather than as ends in themselves. Because of bad experiences, many resource managers have a skeptical attitude toward the use of mathematical models for assessing river quality problems. Consequently, at the outset of this project, the staff spent considerable time determining the reasons for such skepticism and devising a framework for avoiding the pitfalls inherent in many modeling efforts (*16*). As a result, the completed DO model has proven to be sound, and the Oregon Department of Environmental Quality has accepted it as a reliable method for evaluating pollution-control alternatives.

We found that there were several river quality problems that currently are too poorly defined to model in a practical and useful manner. Such problems include trace-metal distribution and the relation between nutrients and algal growth. The project assessed these problems through the development of qualitative descriptive approaches. The results clearly demonstrated that qualitative approaches can provide adequate and reliable information for the management of certain river quality problems.

Changes caused by secondary treatment. The secondary treatment of all point-source discharges in the basin has drastically changed the self-purification characteristics of the Willamette River. The loadings, in-river concentrations, and rates of exertion of BOD were all much lower than in previous times.

The results generally indicate that once efficient secondary treatment has been achieved on all point-source discharges, other causes of DO depletion may become more important than the BOD remaining in the treated discharges. Also, the rate of carbonaceous decay can become so low that, depending on a river's hydrologic character, further reduction of point-source BOD may have little or no effect on DO concentrations (*11*).

Measured BOD concentrations and reaction rates in the Willamette River are approaching those in natural, unpolluted waters. This means that the 5-day BOD test can no longer be used to estimate the impacts of pollution loadings. It is now necessary to conduct 20-day (or other long-term) BOD tests to adequately measure concentrations and to determine reaction rates as a basis for modeling carbonaceous decay.

Nitrification is now a prominent DO sink in the Willamette River. The process was found to occur only in shallow, high-velocity reaches, and within biological slimes attached to rocks (not in the water column). This finding supports a recently proposed hypothesis (*17*) and indicates that assessment of nitrification impacts must consider the physical nature of rivers in addition to ammonia loadings and water temperature.

Implications for Resource Management

Certain findings of the Willamette study could be of great significance to national programs for the management of land and river quality.

The need for localized studies. Rivers and their basins are dynamic, and the processes within them result from the interaction of complex natural factors with the activities of and alterations brought about by human beings. This interaction creates local problems which, once adequately assessed, often have local solutions. Examples in the Willamette River are the relative roles of (i) BOD and nitrification as causes of DO depletion, and (ii) nutrient concentrations and flow as controllers of algal growth.

Without the understanding provided by this study, resource planners might logically have assumed that further BOD removal was a critical priority and that additional treatment of all point sources was necessary to reduce the loading of nitrogen and phosphorus. However, the study showed, first, that nitrification, induced largely by ammonia loads from one industrial source, was a more important cause of DO depletion than waste-water BOD loads and, second, that water-detention time, rather than the concentration of nitrogen and phosphorus, was the primary controller of algal growth.

These examples illustrate that rigid nationwide standards and regulations are likely to result in unneeded expenditures in some basins and in unachieved standards in others. The proper balance can be attained for each river only through an intensive, coordinated assessment that is keyed to local problems and conditions.

The need for alternative strategies. Although waste-water treatment is essential, it is not the sole means of river quality enhancement. Other defensive and offensive strategies are also needed. For example, in the Willamette River basin, two critical needs are (i) low-flow augmentation from reservoirs to maintain desirable summertime conditions of DO, and (ii) land-use management to alleviate the widespread problems that arise from erosion and sedimentation.

Flow augmentation from storage reservoirs is largely responsible for the remarkable improvement in summertime DO concentrations witnessed in the Willamette. Even with the excellent pollution-control program mounted over the years, standards would still be violated in certain subreaches during most summers without low-flow augmentation. During dry years, violations would occur under natural flow conditions over much of the lower half of the river for up to 2 months. These results generally show that low-flow augmentation must be recognized as both a complement to secondary treatment and an alternative to advanced waste treatment.

Aside from point sources of pollution, the quality of a river is largely determined by the interaction between climate, basin-terrain characteristics, and land-use activity. At present, the controlling interrelationships are poorly defined because of (i) inadequate recognition of the linkages between land-use activity and river quality, and (ii) until recently, lack of a suitable means of synoptic terrain analysis of entire river basins. Today, however, there is awakening recognition that economic trade-offs exist between land development and the cost of maintaining desirable river quality. The situation is now such (in the Willamette and most other river basins) that, if land-use activity and land runoff are not brought into the planning picture, the ultimate reality will be land-imposed constraints on river quality.

Good data can save money. Results of the study also indicate that, when expensive management decisions are pending, there is no substitute for carefully interpreted, intensive data. The cost of conducting the DO element of the study was approximately $125,000. Although a considerable investment, it is small compared to the amount that might be spent for pollution control in such a river basin over the next 10 to 20 years. In fact, the U.S. General Accounting Office (*1*) estimated that the results of the study potentially could save tens of millions of federal, state, and local dollars. As costs for waste-treatment facilities continue to rise, it becomes increasingly important to have valid information to discern between effective and ineffective management strategies. Modest investments to obtain scientific knowledge can pay handsome long-range dividends in pollution-control programs.

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Microtubules in Prokaryotes

Universally involved in mitosis and motility in eukaryotes, microtubules are seen in spirochetes.

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Summary. Longitudinally aligned microtubules, about 220 Å in diameter, have been seen in the protoplasmic cylinders of the following spirochetes (symbiotic in the hindguts of dry-wood and subterranean termites): *Pillotina* sp., *Diplocalyx* sp., *Hollandina* sp. They are also present in a gliding bacterium from *Pterotermes occidentis*. These microtubules are probably composed of tubulin, as determined by staining with fluorescent antibodies to tubulin and comigration with authentic tubulin on acrylamide gels. *Treponema reiteri* lack tubulin by these same criteria. These observations support the hypothesis of the symbiotic origin of cilia and flagella from certain spirochetes.

Microtubules, 250 angstroms in diameter, composed of tubulin proteins are universal constituents of eukaryotic cells. They take part in flagella movement (*1*), and in intracellular transport such as that in nerve cells (*2*), protozoans (*3*), hydras (*4*), and fungi (*5*). Microtubules have a role in regenerative morphogenesis (*6*) and underlie many cell structures, especially those in protists and animals (*7*). They comprise the mitotic spindle (*8, 9*) and are intimately involved, in still incompletely known ways, in the segregation of the chromosomes to the poles in mitosis in nearly all eukaryotes (*8–11*). Tubulin proteins from very different sources show a great deal of homology (*12, 13*); most microtubules are sensitive to cold and most bind alkaloids such as colchicine, vinblastine, and lignans such as the podophyllotoxin derivatives (*12–14*). But some microtubules are insensitive to these agents (*15*).

In general, neither microtubules nor microtubule proteins are known to occur in prokaryotic organisms such as *Escherichia coli* or *Bacillus*. However, hollow tubular structures have been reported in cell walls in certain blue-green algae (*16*). Smaller tubular structures have also been reported in *Proteus mirabilis* and in *Treponema*, but not in *Borrelia* (*17, 18*). None of these prokaryotic tubules have been studied chemically. Microtubules have not been observed to be involved in prokaryotic cell division.

There are two classes of hypotheses for the origin of eukaryotic microtubules. The exogenous (*19*) hypothesis suggests the origin of tubules in eukaryotic cells by symbiotic acquisition of tubule-containing spirochetes. Originally selected because associated spirochetes conferred motility on their hosts, as time went on the spriochetes evolved into the ubiquitous (9 + 2) flagella or cilia (undulapodia) (*20*) of eukaryotes. If such ancestral spirochetes have not become extinct, it is expected that free-living descendant spirochetes, ancestors to the (9 + 2) flagellar organellar system, will be found and that these will contain microtubules. These hypothetical tubules are predicted, therefore, to be composed of tubulin proteins and to be homologous to those in eukaryotic cells. The endogenous hypotheses of Pickett-Heaps (*11*) and Taylor (*21*) of the origin of tubules suggests that tubulin differentiated in primitive photosynthetic organisms ancestral to modern red algae.

Electron Microscopy

The observations (*22, 23*) of intracytoplasmic microtubules, 250 Å in diameter, in large spirochetes—such as those in the hindguts of termites—did not come to our attention until 1972. Hollande and Gharagozlou placed the microtubule-containing spirochetes in the genus *Pillotina* and in a new family, the Pillotaceae. The difficulty of obtaining the termite host endemic to the island of Madeira limited further work until these same pillotinas were recognized in electron microscopic (EM) preparations of *Reticulitermes flavipes* (*24*). Since 1974 we have found the large distinctive pillotina spirochetes and their smaller hollandina relatives present in hindgut microbiota from 21 out of 21 species of dry-wood termites [family Kalotermitidae (Fig. 1)], from five out of five species of subterranean termites (family Rhinotermitidae, for example, *R. flavipes*, *R. flavicollis*, *R. hesperus*, and *Heterotermes aureus*), but absent in two out of

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