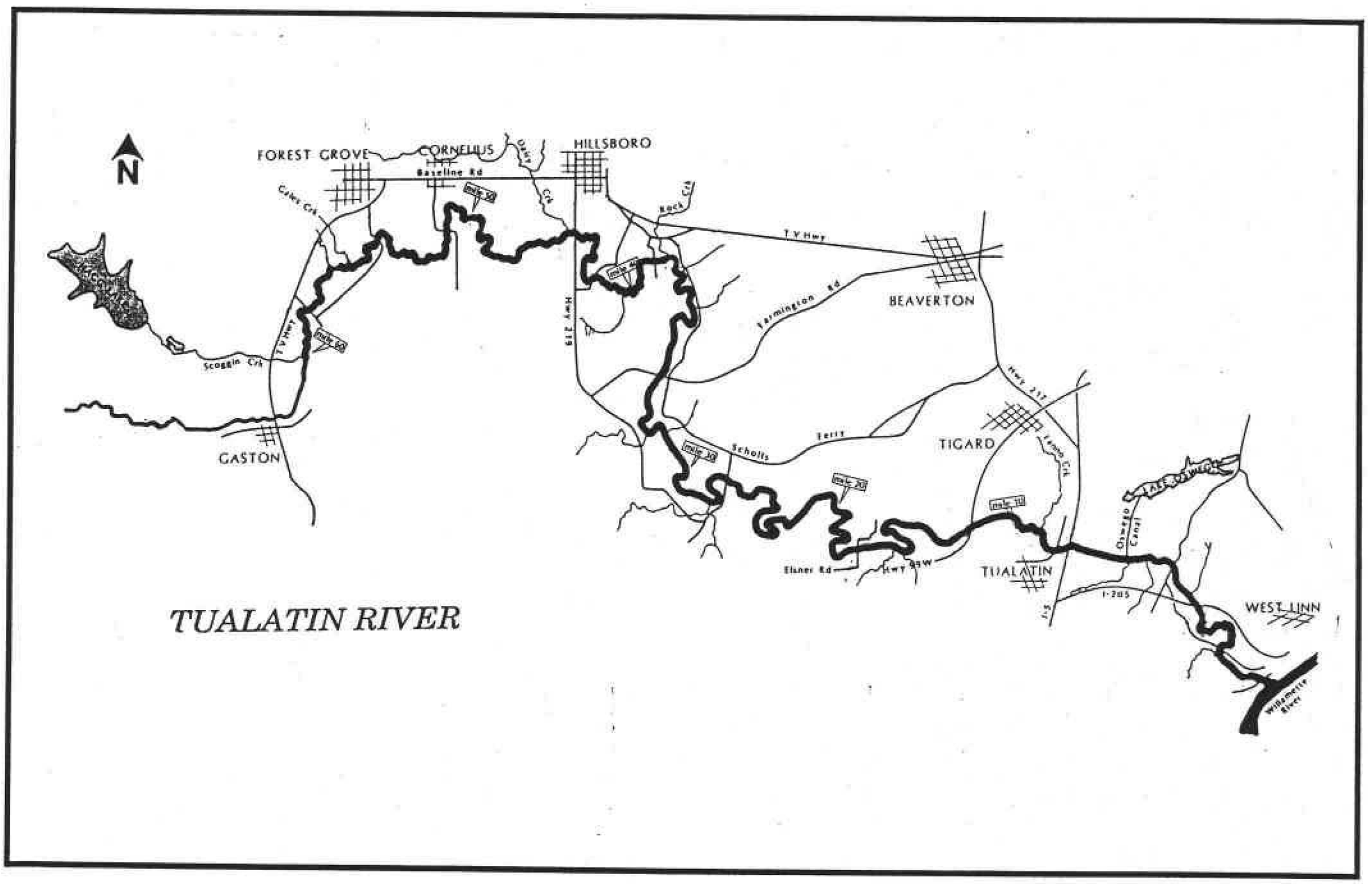
Evaluation of Alternative Pollution Control Strategies for the Tualatin River Basin, Oregon



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FORWARD

This report summarizes the conclusions reached in "A Project to Collect Scientific Data and Provide Evaluation and Recommendations for Alternative Pollution Control Strategies for the Tualatin River Basin."

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The detailed analyses are given in supplementary reports, listed in the appendix.

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EXECUTIVE SUMMARY

This project has been carried out by a multidisciplinary team at Oregon State University and Portland State University in response to an Oregon Department of Environmental Quality request to bring together the available information on water quality in the Tualatin Basin, to analyze the information and to present it in a form that would be useful to decision makers. The information has been summarized in the form of alternative actions that can be taken to improve water quality. The project did not include any further research into questions of the amounts of nonpoint source phosphorus entering the stream from different land uses, or into the dynamics of phosphorus supply for algal growth.

The Tualatin River Basin has seen major changes in the past 150 years. Before that time, the Basin was characterized by extensive areas of wetlands that contributed to summer flows and removed nutrients before they entered the River. Harvesting timber and the removal of native vegetation and draining of wetlands for agricultural use started about 150 years ago. Major urbanization in recent years increased impervious surfaces, with consequences for river flow. Destruction of riparian vegetation occurred with changing land uses. Formation of the Unified Sewerage Agency with state-of-the-art sewerage treatment facilities and reservoir storage on Hagg Lake resulted in major improvements in river water quality. However, continued growth in the Basin added pollutant loads, so the River did not reach the quality required for beneficial uses. The Total Maximum Daily Loads (TMDLs) set for ammonia have been achieved during the summer because the point sources could be eliminated, but the nonpoint sources of phosphorus have been much more difficult to control.

Increasing the quality of the Tualatin River is not simply a matter of meeting TMDLs for phosphorus, but requires a comprehensive restoration of health of the watershed. It must include restoration of riparian functions, with vegetated riparian areas and more wetland areas to enhance water quantity and quality. It will also include health of biota, and decisions such as whether the River should be managed for warm water or cold water fish. There has been no systematic study of biota in the Basin; this is needed as a baseline for planning the restoration of biological functions of the River. Similarly, systematic studies of trace amounts of potentially toxic organic and inorganic pollutants should be carried out to evaluate the potential chronic effects of toxics on river health.

Four categories of strategies were developed to improve Tualatin River water quality: augment summer flow, decrease phosphorus load, modify stream corridor, and change in-stream processes. Technical and economic evaluations of the alternatives were made. The social aspects of the alternatives must be taken into account by decision-makers through the political process.

Seasonal algal blooms are one of the major reasons why the water quality in the Basin does not meet all beneficial uses. The growth of algae requires an adequate supply of nutrients as well as adequate temperatures and residence times in the water. Decreased algal growth will come from changes in one or more of these factors. Increased water flows during the summer, with estimated requirements of at least an extra 100 cubic feet per second during the months of July and August, may be technically the easiest to provide, although not inexpensive. These extra flows will dilute phosphorus concentrations and decrease residence time in the lower Tualatin River pool area. They could also decrease water temperature.

Phosphorus loads from point sources have been decreased and best management practices for crop and animal agriculture, as well as for urban runoff, will decrease nonpoint source phosphorus loadings. The magnitude of this decrease cannot presently be determined because the proportion of phosphorus coming from subsurface flow has not been determined. It would appear to be difficult to decrease nonpoint phosphorus inputs to 50 percent of present levels, a level that would be required to decrease growth of algae. Urban nonpoint sources are significant and control is possible through management of stormwater by, for example, treatment on land.

Stream corridor management includes restoration of riparian vegetation to trap sediments and remove nutrients from surface and subsurface flows into the River. Riparian vegetation also decreases water temperature and decreases light reaching the stream. In-stream processes can be modified through mechanical means such as aeration, which would increase dissolved oxygen and prevent thermal stratification.

Two models were calibrated and used to evaluate the alternatives. The loading model (HSPF) has been widely used and is supported by the Environmental Protection Agency. It is able to simulate the land processes relating to water quality. The river model, CE-QUAL-W2, takes the input from the loading model and predicts changes in the River as a result of different loadings.

Recommended actions include providing supplemental stream flows, continuing aggressive implementation of nonpoint source management programs, and continuing to engage the public in long-term planning. These actions will slow further deterioration of water quality; they are not sufficient, with continuing growth in the Basin, to provide the water quality required for beneficial uses. Further actions include restoration of riparian vegetation, restoration of water storage in the landscape, for example in wetlands, and source reduction through changed management of land in urban and agricultural areas.

The detailed studies are contained in a series of Tualatin River Basin Water Resources Management Reports, available from the Oregon Water Resources Research Institute, Oregon State University, Corvallis, Oregon (503-737-4022).

INTRODUCTION

In response to House Bill 3338, the Oregon Department of Environmental Quality in 1991 released a request for proposals to compile and analyze available information on water quality in the Tualatin River Basin. The report would provide a scientific basis for improving basin water quality and would present the information in a form useful to decision makers.

We have analyzed available information and summarized it in the form of alternatives suggested for improving water quality. These alternatives were evaluated using information on land interaction processes and on river flow processes. All the alternatives have costs and benefits, some of which are included here and some of which must be weighed by the decision makers in the political process that includes values held by the people involved.

The project did not include any further research into questions of water quality in the Tualatin. The Unified Sewerage Agency (USA), the U.S. Geological Survey (USGS), and the Oregon Department of Environmental Quality (DEQ) provided most of the data. Research needs to continue because there are important unanswered questions related to how the nonpoint source phosphorus reaches the streams, and to the dynamics of phosphorus supply to algae.

The Tualatin River Basin covers approximately 700 square miles, mostly in Washington County. The upper reaches of the Tualatin River and its tributaries are in steep forested terrain, producing timber and providing wildlife, recreation, scenic and water collection values. This area covers nearly half the basin area. The lower reaches are broad alluvial valleys with fertile soils and good climate where land use is for agriculture, small residential farms and rural residences as well as urban uses. About 40,000 acres are in irrigated crop land, 55,000 acres in non-irrigated crop land, and about 60,000 acres in pasture.

Figure 1. Tasslecap photograph of Tualatin Basin from Landsat satellite imagery, 1988. 30 meter resolution. Dark blue = water; Light blue = Forest/trees; Red = agricultural lands; Purple = asphalt.

Increasing population and urbanization has led to a gradual increase in loading of nutrients and pollutants to the River. Organization of the Unified Sewerage Agency, with modern waste treatment facilities, led to large improvements in quality of the wastewater effluent in the 1970s. Continuing improvements in the process have lowered the effluent concentrations of nutrients. Ammonia, which comes largely from the effluent, has been effectively removed at the treatment plants by converting ammonia to nitrate. The concentrations of phosphate have been decreased through wastewater treatment improvements, through elimination of most of the phosphorus coming from household detergents, and most recently through a biological phosphorus removal procedure at the treatment plants that has been proven to be very effective during the summer. The effective removal of point sources of phosphate leaves nonpoint sources as the major phosphate loading to the Tualatin River in the summer. At the same time, best management practices are being put in place to decrease nonpoint sources of phosphate due to erosion from agricultural activities, pollution from confined animal feeding operations, from forestry activities, and from urban activities including stormwater management and construction site erosion management. Some of these are voluntary, some are mandatory.

Even with these changes, water quality in the Tualatin Basin is not meeting, at all times, standards required for the beneficial uses. The need for water quality control remains.

Until recently water quality control has been based on use of best available technology for controlling point sources of pollutants. When a water body does not meet beneficial uses with the application of best available technology, a water quality-based standard must be used. This is the Total Maximum Daily Load (TMDL). The Tualatin River falls into the category of water bodies that do not meet the required standards with best available technology, and hence TMDLs were set for ammonia and phosphorus.

Ammonia comes from point sources and has been largely controlled by oxidation to nitrate in the waste water treatment process. Phosphorus often remains the major nutrient of concern. Phosphorus comes from both point and nonpoint sources. Point sources have been decreased dramatically within the past few years to where nonpoint sources are now the larger contribution. Background sources of phosphate are now seen to be very important. It is not known at this time what proportion of nonpoint source phosphorus comes from urban, from agriculture and from forestry land uses, or what proportion reaches the stream attached to sediments and what proportion comes as soluble phosphate in subsurface flow into the River.

There is not a simple, specific, technological answer to management of water quality in the Tualatin Basin. The cumulate effects of many activities have led to the problem, and will continue to intensify the problem. Solutions lie in many changes in management of river flows and management of land surfaces. Each of these changes has costs and benefits, but changes must be made or each small cumulative impact will continue to add to overall degradation of water quality in the Basin.

HISTORICAL PERSPECTIVE

The landscape of the Tualatin River has undergone extensive change since the initiation of Euro-American settlement in the early to mid-nineteenth century. These changes have important consequences for the hydrology and water quality of the Tualatin River. Water quality in the lower reaches of the River has become a concern within the latter half of the twentieth century.

Landscape characteristics are important to basin hydrology and plant nutrient dynamics. The most important characteristics are:

* The physical complexity of the stream channel and interactions with adjacent floodplains.

* The presence and integrity of wetland environments which include riparian wetlands, freshwater marshes, and freshwater swamps.

* The amount of developed urban areas with their associated impervious surfaces.

Three major types of landscape change have occurred within the Basin:

* The isolation of the Tualatin River from its floodplain and associated losses of riparian areas and related wetlands.

* The draining and conversion of wetlands to agricultural and other developed land uses.

* Urbanization and covering water retentive soils in the Basin with impervious surfaces.

These changes have produced both a landscape that is functionally different from that experienced by the early explorers and a river system that responds to different impacts and as a result displays a different set of water quality symptoms.

The first descriptions of the Tualatin Basin landscape are credited to Hudson's Bay Company trappers who explored the Willamette Valley and Oregon Coast in search of beaver. A trapping party headed by Alexander R. McLeod crossed the Basin in the spring of 1826. Their route was along "the Borders of the Mountain" because of wet conditions in the valley floors. Early roads were generally along the valley sideslopes to avoid those wet areas. About the same time, Peter Skene Ogden, another Hudson's Bay Company trapper and explorer, described the Tualatin Valley as "mostly water connected by swamps." Local flooding was attributed to beaver and to "accelerated sediment, fallen trees, and living vegetation in the channels." The "general description" from the 1850s of Township 1 South, Range 3 West, Willamette meridian by federal land surveyors reads:

> On both sides of the Tualatin River are some bottom lands which are subject to inundation to the depth of 10 or 12 feet and have a sandy soil timbered with fir, ash, maple, vine maple. . . . These bottoms have many swamps principally [sic] caused by beaver dams on the small streams. The timber in the swamps is principally [sic] willow from 10 to 20 feet high and so thick they are almost impenetrable [sic].

Transformation of the pristine or pre-contact landscape of western Oregon has been attributed to activities related to the timber industry, navigation improvements, agricultural development, and urbanization. Drainage of wetlands and changes in flooding pattern of the River were carried out to develop land for agricultural uses. Examples are abundant of how development has prompted stream channels to be confined, woody debris removed, wetlands drained, and surfaces paved. Population figures alone are sufficient to appreciate the pressures on the Tualatin River Basin landscape. The growth of population of Washington County was as follows:

Year	Washington County Population	State of Oregon Population
1850	2,652	12,093
1900	14,467	413,536
1950	61,269	1,521,341
1990	311,554	2,842,321

Much of the change in the pre-contact landscape of the Tualatin Basin has been in the Basin's lowland streams and wetlands. Although it is difficult to predict precisely the quantitative impact of these changes on the water quality in the lower reaches of the stream, these alterations have reduced hydraulic residence time at both the local and basin scale, have eliminated features that contributed to nutrient processing and storage, and changed the susceptibility of agricultural and other soils to water erosion. The net effect of these changes would be to reduce the summertime baseflow in the River, to increase the residence time of water in the lower pool, to increase the nutrient (phosphorus) content of the water in the stream and to permit additional sunlight to shine on the stream. This situation has been further exacerbated by the Lake Oswego diversion dam which increases the size of the pool and increases the residence time of water in the pool. All of these factors contribute to growth of algae in a quiet pool.

Extensive efforts have been devoted to improving the quality of the Tualatin. Currently, the Unified Sewerage Agency (USA) provides a degree of sewage treatment beyond that in any other river watershed in the country. The municipalities and other Designated Management Agencies (DMA) within the Basin have conducted an aggressive educational effort to prompt the public to make responsible water-protecting decisions. There is a street sweeping and catch basin cleaning program in place. Construction sites are required to provide erosion control. Forestry and agriculture have adopted erosion control efforts; steps have been taken to minimize adverse water quality impacts related to animal husbandry. In spite of these Herculean efforts by the DMAs, algal blooms with associated dissolved oxygen swings occur several times each summer and the stream has a turbid appearance much of the year.

A watershed management plan for the Tualatin Basin will need to consider the importance of the landscape features that have been altered by human activity. Stream habitat improvement and wetland mitigation activities would assist in restoring water quality in the Tualatin Basin, would provide important habitats for fish and wildlife and would enhance a number of other values associated with aquatic and wetland environments.

AQUATIC HEALTH OF THE RIVER

1. The Tualatin Watershed

An evaluation of water quality in the Tualatin River cannot focus simply on water chemistry and on achieving the TMDLs for ammonia and phosphorus. A river has functions within the landscape. The ecological, aesthetic, and cultural values must be included in the evaluation of a river. We now view rivers not just as conduits for supply and removal of water, but in a holistic view of the landscape, finding out how they function and designing our necessary economic activities around these functions. This is sustainable development.

The processes of water and sediment transport through the watershed determine watershed functions. The nature of the uplands and the land use management on the uplands determine amounts, timing, and quality of sediment and water. The characteristics of the channel, including slope, geology and interaction with vegetation, determine how water and sediment are transported along the stream. Many of our necessary economic activities influence these functions.

The health of a river includes the various biological functions. Fish populations are an important and visible part of these ecological functions, but only one part.

The public participation process that was part of this project provided information on what people want from the River. Recreation, and the River as part of the landscape, come out strongly as public requirements.

An evaluation of the historic Tualatin River has shown that previously the River interacted more with the surrounding land. Wetlands, with important water quality functions, were previously much more common in the Basin. The disappearance of wetlands has been part of the process of land use changes, all of which affect the function of the River. Some of the changes by themselves may not produce a measurable effect, however, the cumulative effects of the many changes in land use have changed the functions and the appearance of the River. We need to think in terms of cumulative effects, rather than evaluating each action separately.

For the last 150 years, the Tualatin River Basin has been central to development in the upper Willamette Valley. Historical splash dams associated with timber harvest, water diversion at Lake Oswego, drainage of wetlands for agricultural production, regulated flow by Scoggins Dam and major land use changes first to agricultural and then to urban uses have changed hydraulic and geomorphic processes in the Basin. Agriculture, forestry, and urban uses have fragmented the landscape, resulting in further degradation of stream function. Biological recovery of the Basin will depend on changing some of these landscape alterations. Baseline biological data is needed across the entire basin to assess present conditions as a basis for management.

2. Watershed Health

Riparian zones of tributaries and the mainstem are fragmented, affecting all levels of stream function. Riparian vegetation intercepts sediments and nutrients and also influences stream temperatures and light levels. Restriction of floodplain function by agricultural and urban development prevents the River from exchanging sediment with adjacent banks. Historical snag removal has altered potential habitats for biota, making remaining large wood from riparian zones valuable resources for channel structure. Connections between riparian zones are essential for wildlife, whose ranges often exceed the patchy distribution of remaining riparian areas. Restoration should include reconnecting riparian zones both longitudinally and laterally with adjacent floodplains. Recognition of floodplain function should play a role in future planning decisions for the watershed.

3. Biota

Surprisingly little is known about the biota of the whole Tualatin Watershed. Emphasis has been placed on the lower mainstem; very little information has been gathered for tributaries. Data on algae are generally confined to phytoplankton in the lower mainstem, with scant data on benthic periphyton. A shift from blue-green algae in 1976 to filamentous diatoms in 1987 may indicate improved water quality during that interval. Abundant aquatic herbivores in the mainstem, primarily zooplankton and suckers, are important biological controls for algae.

Trophic dynamics of resident and migrating fish are affected strongly by the thirteen species of non-native, warm water fishes that are predators on zooplankton and other fish. Winter steelhead are introduced as hatchery fish in most tributaries, but Gales and Dairy Creeks are now being managed for only wild cutthroat trout. Little is known about the abundance of fish in the tributaries. Management policies should distinguish native from non-native species, and recognize that recovery of native communities may be retarded by enhancing exotic species.

Though species lists for riparian vegetation and wildlife have been developed for localized areas, distributions of terrestrial biota are poorly understood, and little quantitative documentation exists. Loss of habitat of woodlots, fence rows and riparian zones has contributed to declines in wildlife. However, wetland restoration has been very successful in attracting waterfowl. Popularity of these areas attests to the potential of nature-watching values in future restoration plans for the Basin.

4. Toxic Substances

Systematic and detailed measurements of potentially toxic organic and inorganic chemicals have not been made for the water column, for sediments or on biological tissues. A number of chemicals have been found, generally at higher concentrations in the lower mainstem compared with the upper parts of the River. They do not reach health advisory levels, but indicate the need to look for chronic effects on health of the River.

5. Sediments

A steady-state mass balance model for suspended solids was used to characterize sediment inflow, outflow and any sources/sinks along the River. The River was divided into twelve sections based on the monitoring stations of the Unified Sewerage Agency and all tributaries were treated as point sources flowing into one of these segments. Data from several agencies over the period 1990-1992 were used. A significant portion of the sediment was found to enter the River from the upper half of the Basin above river mile 39. Dairy and McKay Creeks were found to contribute significant solids loading. The seasonal variation of solids loading was as much as a factor of ten, with loading being low in summer. The changes observed in the lower part of the River, between river mile 39 and the mouth of the River, tended to remain local and did not account for any major change in the River.

6. Restoration

The Tualatin's future will depend on balancing needs of agriculture and urban growth with ecological management of water, soil, plant, and animal life resources. Criteria for restoration should include values of longevity and stability, recognizing economic, recreational, and aesthetic priorities. The criteria of floodplain process recovery and return of native biota to more expanded ranges provide high standards for restoration.

NATURE OF THE PHOSPHORUS PROBLEM IN THE TUALATIN RIVER

1. Problem Description

During the summer months of high sunlight intensity, warm temperatures, low stream flows, and long detention times in the Tualatin pool, conditions are right for algae to grow to excessive levels. These levels cannot be maintained during cloudy conditions, and the algae die. Thus algae grow, turn the River green, then die causing it to look brown, and to suffer lowered oxygen concentrations that stress fish. These conditions cause that segment to be in violation of the water quality standards and make the River less desirable to people living near it.

2. Factors Affecting Algal Growth

Excessive algal growth is characteristic of eutrophic, or nutrient-rich water bodies. The most common growth-limiting nutrient in fresh waters is phosphorus. This implies that decreasing the availability of phosphorus in the River can decrease algal growth.

Other factors important in controlling the growth of algae are light, temperature, and time. High turbidity levels can reduce light penetration in the water column and limit algal growth to a shallow zone near the surface. Light can also limit algal growth in cloudy weather. Cold water temperatures reduce algal growth rates such that, combined with lower light intensity and greater water flow rates, excessive algal production is not a serious problem during the non-summer months. Travel time refers to the length of time for water to flow through a section of the river. Greater travel times mean longer exposure to light, higher water temperatures and resultant greater algal growth. Figure 2 summarizes some of these relationships.

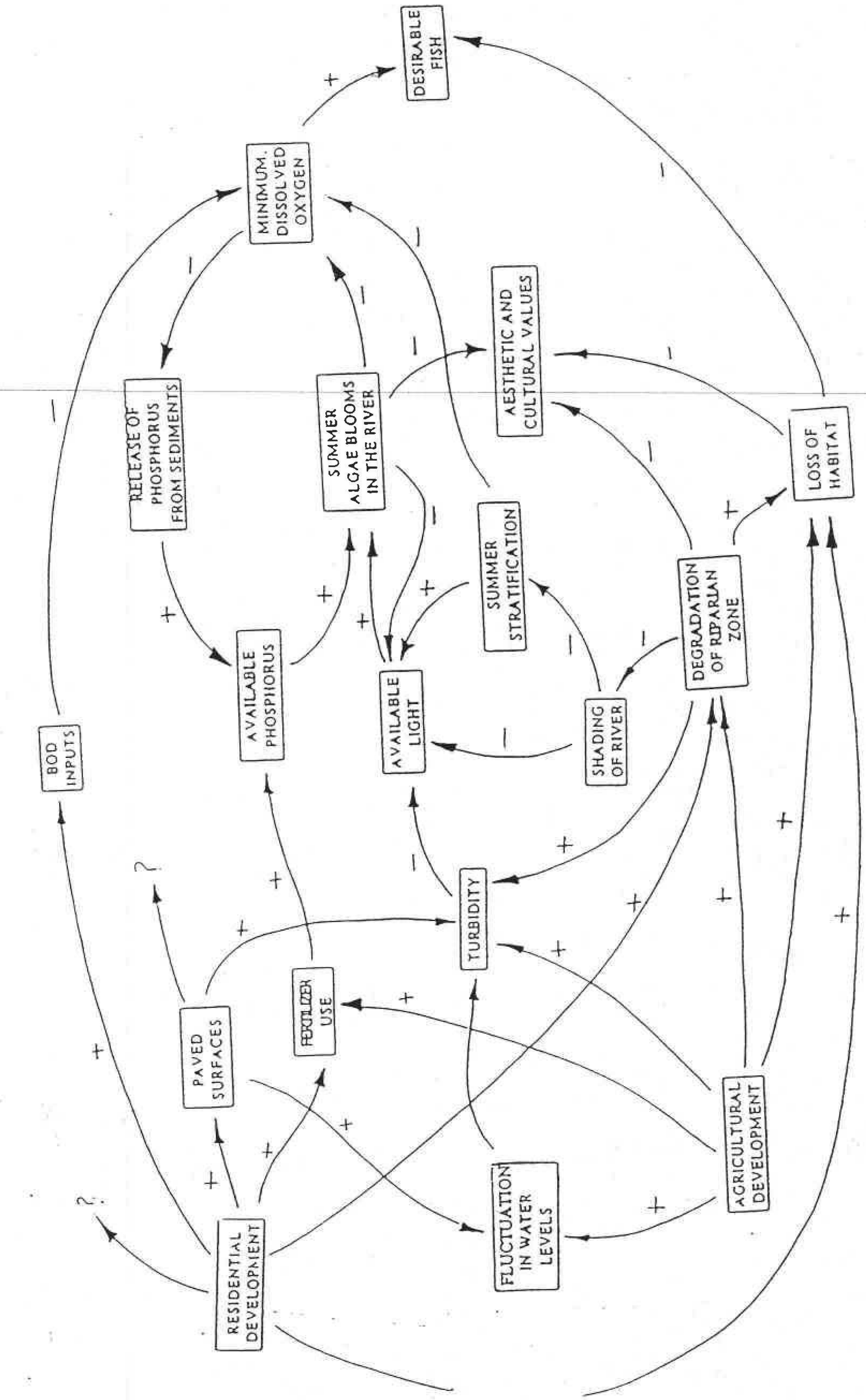

Figure 2. **Processes affecting growth of algae in a stream.**

This figure demonstrates some of the many complex relationships for the biology of the Tualatin River. The figure may be entered at any box. Moving with the arrow shows the impact of the action in the box. Moving counter to the arrow shows cause and direction.

3. Forms of Phosphorus

The total phosphorus concentration (total-P) in water may be divided into that associated with suspended particles (particulate-P) and that which is dissolved (soluble-P). Soluble-P is the most available for algal assimilation; it includes ortho-phosphorus (ortho-P), condensed phosphorus forms such as polyphosphates, and organic phosphorus forms such as proteins from organic wastes. Condensed and organic phosphorus is readily converted by hydrolysis and enzymatic reactions to ortho-P.

Particulate phosphorus includes organic particles such as bacterial and algal cells, organic macromolecules, other organic matter fragments and inorganic particles such as precipitated mineral phases. Particulate phosphorus is not directly available for algal assimilation, but must first be converted by bacterial degradation and natural dissolution processes to soluble-P. This conversion is enhanced by anaerobic conditions in the sediments.

4. Relationship to Water Quality in the Tualatin

The Tualatin River, because of its physical geography and land use patterns has elevated phosphorus concentrations combined with high available light, warm temperatures, and long travel times (low flows). Explosive growths of algae, algal blooms, occur during particularly warm, sunny periods, followed by crashes due either to changes in conditions (cool, cloudy) or to nutrient depletion. These bloom-crash cycles typically occur in the section of the River impounded by the Lake Oswego diversion dam. Algal growth reduces water clarity and causes the water to have a green hue, conditions that are generally considered unacceptable for recreational and aesthetic uses of the River. During decomposition of algae, oxygen concentrations decrease rapidly and anaerobic or low dissolved oxygen conditions develop. Anaerobic biodegradation processes generate gases and organic acid intermediates, greatly detracting from the biological health and aesthetic values of the River. Phosphorus in decaying algal cells is released back into the water column where it may be recycled, promoting future algal growth.

Stratification in the deeper pools of the lower River, where a warmer upper layer, the epilimnion, is separated from a cooler lower layer, the hypolimnion, aggravates the effects of algal blooms and crashes. Mixing throughout the water column is inhibited by the density difference of the two layers. Re-aeration only occurs in the epilimnion, and the hypolimnion can become severely reduced in oxygen concentration, eventually turning anaerobic. Low or depleted oxygen concentrations cause stress or are lethal to much of the biological community in the River, greatly limiting its diversity.

5. Hypotheses for Factors Controlling Algal Blooms in the Tualatin River

Phosphorus and light limitation have been advanced as factors that control the occurrence of algal blooms in the Tualatin River. Elevated water temperatures also promote more rapid algal growth. The phosphorus-limitation hypothesis assumes that algal growth is limited by the availability of phosphorus. Hence, lowering phosphorus concentrations in the River should reduce algal production and improve water quality, particularly clarity. Diurnal oxygen fluctuation should be of lower amplitude. In stratified sections of the River, hypolimnetic oxygen depletion should be lessened, and anaerobic recycling of phosphorus reduced or eliminated.

The light-limitation hypothesis assumes that algal growth is limited by the availability of light for photosynthesis. In non-stratified sections of the River, mixing occurs throughout the water column. For algae to photosynthesize and grow, cells must spend sufficient time in the euphotic zone where light penetrates. Turbidity in the water reduces light penetration and hence algal growth. In stratified sections of the River, algal growth is generally not light-limited, as algae are retained in the euphotic zone. Algal blooms result.

The Tualatin River monitoring data confirm that algal blooms are promoted by increased water temperatures, elevated phosphorus concentrations, and by long residence time in the low-velocity pool. Water in the lower Tualatin is warmed by increased residence time, lack of stream shading, runoff from warm pavement and roofs as well as from the ambient air.

6. Potential Alternative Mechanisms

Previous efforts to control pollution of the Tualatin River, and the basic strategy of this study, have been based on the traditional concept of loads entering a stream and the stream responding to those loads. Environmental science is sufficiently well developed that we as practitioners can predict the stream responses and write models to incorporate the many factors we can describe.

The water quality impacts that affect beneficial uses of the Tualatin are related to low stream flows. These include long retention times, warm temperatures, and an adequate nutrient supply. Since these occur during the summer months, a load management strategy and TMDL limits have been established which are based on the assumption that dry weather loads entering the stream create the environment for rapid algal growth.

There is another possibility, unproved but having a rational basis. This other possibility is that wintertime phosphorus associated with higher streamflows accumulates on sediment particles at the stream bottom and at the sides. It is possible that these sediments, whether mobile or stationary, could be "loaded" with phosphorus during the winter, higher flow period. These storage sites could then conceivably release the sorbed phosphorus during the low flow periods when temperatures are higher and dissolved oxygen concentrations are lower.

The implication of this alternative, if it reflects reality, is the need for a much greater emphasis on the control of wintertime pollutant loads. These wintertime loads are both expensive and difficult to manage. They include wintertime erosion, streambank erosion, and wintertime sewage. The good news is that the short and long term strategies recommended in this report will effectively respond to the summertime symptoms of wintertime pollution. The bad news is that the strategy treats only the symptoms and not the basic causes.

Unfortunately, current knowledge does not resolve this question. Given this uncertainty, it is the best advice of the investigators that the regulatory process move ahead based on the best understanding of today, but with a commitment to incorporate new information as it becomes available.

MODELS FOR WATER QUALITY

Computer models describing the physical, chemical, and biological processes on the watershed and in the streams were used to evaluate the effectiveness of various strategies to improve water quality of the Tualatin River Basin. Watershed processes that result in the transport of nutrients, particularly phosphorus, to the River system and the transport and transformation of these nutrients in the River are the main concerns. Most models to simulate various water quality processes have been developed for specific purposes and do not represent the full range of processes representing the watershed and the River.

Existing computer models were evaluated by the project team and two models were selected for use in this study: the Hydrologic Simulation Program FORTRAN (HSPF) model for simulations of the watershed and tributary streams and the CE-QUAL-W2 for the mainstem of the Tualatin River.

1. HSPF Model for Nonpoint Source Loading

This model has been developed over a number of years and is supported by the U.S. Environmental Protection Agency. The model represents the various hydrologic and water quality processes through equations based on a combination of fundamental physical and chemical concepts and principles and empirical expressions. It has been widely used and accepted.

HSPF considers the watershed and stream system as a network of elements or segments that represent an area of pervious land, an area of impervious land or a length of stream. The Tualatin River Basin was subdivided into the 28 subbasins used by DEQ in setting the TMDLs. This excluded the Lake Oswego subbasin. On the pervious land segments, all relevant hydrologic processes are simulated to provide an accounting of the water balance, including interception by vegetation, infiltration into the soil, percolation of water downward through the root zone into the lower zones of the soil to the water table, evapotranspiration from the upper zones of the soil, overland flow of water that does not enter the soil, and subsurface flow and groundwater flow both into and out of the segment. Physical properties of the segment including catchment area and land slope are used to describe each segment. In addition, a number of parameters that control the rates of the various hydrologic and water quality processes must also be specified. On an impervious segment, water runs off by overland flow or is evaporated from depression storage.

Water quality processes simulated on these segments are sediment detachment and transport, soil temperature, water temperature, dissolved gases, pesticide transport and nitrogen and phosphorus transport and transformation. The model provides a one-dimensional simulation of the water in the stream system as well as the transport and transformation of the constituents delivered from the watershed segments. Physical characteristics are determined from maps of the watershed and the parameters are specified either by association with known properties of the watershed or through calibration, where parameter values are adjusted to make the model reproduce observed data.

Details on the model runs are available in a separate report in this series. The results were used in evaluation of the alternatives.

2. CE-QUAL-W2 Model for River Hydraulic and Water Quality Processes

A modified version of the U.S. Army Corps of Engineers CE-QUAL-W2 hydrodynamic and water quality model was chosen. This is a two-dimensional, laterally averaged, dynamic model of hydrodynamics and water quality, able to predict water surface elevations, longitudinal and vertical velocities, and more than 20 water quality parameters. The model was setup for five river sections: Hagg Lake, Scoggins Creek, Tualatin River from river mile (RM) 60 to 32, from RM32 to 3.5 (diversion dam), and RM3.5 to RM0.0 at the Willamette River. Dynamic records of flow, pollutant concentrations for each point and nonpoint source, water withdrawals (location and quantity) such as Tualatin Valley Irrigation District (TVID) and the Lake Oswego Canal, and meteorological conditions were required as boundary conditions for the model. Details on the model runs are available in separate reports.

ALTERNATIVES AVAILABLE TO RESPOND TO THE PHOSPHORUS/ALGAE PROBLEM

The issue for which the TMDL process was initiated concerns the excessive growth of algae and the associated and uncontrolled variations in dissolved oxygen associated with periods in which algae flourish and periods in which they die and decompose. Four basic strategies, individually or in combination, could be used to prevent large concentrations of algae.

1. The Strategies

A. Increase the Summertime Flow

Increasing the summertime flow rate will result in shorter water residence time in the quiescent lower Tualatin pool. This shorter residence time means there will be less time for the growth of algae. The increased flow, assuming it is of the water quality currently provided by the discharge from Scoggins Reservoir, will also dilute the current phosphorus concentrations. This lowered nutrient level will further constrain algal growth.

Depending upon the time required for the River to reach thermal equilibrium with air temperature, additional summertime flow could maintain a lower water temperature in the pool. Algal growth is stimulated by increasing temperatures, thus, the additional water with its lower nutrient concentration, possibly cooler temperature and shorter residence time will result in lower algae populations.

B. Decrease the Phosphorus Load

Where phosphorus limits algal growth, reducing the phosphorus load will also improve water quality by decreasing excess algae production. The amount of point source phosphorus entering the Tualatin has been reduced, but these reductions have not sufficiently reduced the available phosphorus to substantially change the algae dynamics. Nonpoint source phosphorus is now a main component of the available phosphorus.

Nonpoint sources are land managed for urban, agriculture, and forestry uses. How that land is managed and how streambed corridors are maintained all influence how much sediment and associated phosphorus enter the stream during rainfall and snowmelt events.

Extensive urban development has brought erosion during construction, runoff from impervious surfaces and rapid drainage of highly fertilized lawns and gardens in the Tualatin Basin. These contribute to the phosphorus load with which the River must contend. Urban pollution prevention and abatement measures are available and are being pursued. This process will need to be intensified if long term remediation is to result.

A highly intensive agriculture of field and horticultural crops has developed in Washington County. This includes the intensive production of high-value ornamental plants sold for use around the country. The small residential farm with its associated small animal population is another phenomenon of the twentieth century. These animals may include a recreational horse or a few cattle. There are also commercial animal enterprises in the County. Each of these activities can be a source of nutrients to the streams. It is necessary that the procedures being put in place to minimize nutrient losses be continued, no matter what other steps are initiated.

Forest practices in commercial production, such as road building, are regulated. Forest harvest in urban areas can also be a source of sediment with associated phosphorus.

C. Restore the Stream Corridor

Wetlands and highly vegetated streambank corridors typified the Tualatin River Basin when early settlers arrived. The challenges to these first settlers were to remove the forest cover, rip out the beaver dams and drain the wetlands. These natural vegetation features are critically important to quality of the landscape and to quality of the water. They increase summertime stream flow volume, remove nutrients and keep the soil particles in place. Any long term strategy for restoration of the Tualatin Basin must include protection of the remaining wetland and riparian vegetation and restoration of those features in critical areas where they have been destroyed.

D. Change In-Stream Processes

Stratification of temperature in the River could be decreased by mechanical aeration and mixing, which would make water conditions less suitable for growth of algae.

E. Continue Present Activities

Point sources of phosphorus and heat are being managed. Nonpoint sources of sediment are being regulated. While it does not appear that these measures will be sufficient to control algal growth, the non-change option is available.

2. Evaluation of the Strategies

The different measures under each general strategy were analyzed for technical feasibility, anticipated effects on river aquatic health, expected economic costs where available, and finally the possible political and social impacts of implementing the measures. The primary purpose of the analysis is to identify order-of-magnitude cost effectiveness of the alternative measures to reach TMDL targets. The changes in resource conditions not amenable to economic quantification are described qualitatively. Economic benefits have not been estimated for resource quality improvements, such as increased recreation use. Their omission does not imply lack of importance. Rather, the study's focus is cost effectiveness of meeting the TMDL targets.

This analysis of alternative strategies provides information to policy makers and the public to gauge impacts and tradeoffs. Assessments of the social desirability of one strategy over another are not made by the study team. Those judgments, and policy choices, properly remain with the individuals and groups politically responsible for water quality management. It is assumed in this analysis that all activities affecting water quality, agriculture, forestry, and urban will meet existing legislative requirements such as the Forest Practices Act and Confined Animal Feeding Operation statutes.

A. Augment Summertime Flow

Estimates from the in-stream water quality model suggest that a volume of more than 12,000 acre feet of storage is necessary to produce the additional 100 cfs flows in July and August necessary to approach the TMDL for phosphorus. Stream flow alteration has traditionally been achieved through constructed devices and systems, such as Scoggins Reservoir. Other options include changes in management (e.g., timing) of existing water flows to reduce quality problems. Four groups of measures to increase summertime flow were found to have sufficient potential to merit evaluation. They are presented in order of magnitude of increasing expected costs.

i) Divert water from western slopes

Plans are moving forward to enlarge the capacity of Barney Reservoir on the Trask River. The added 16,000 acre feet of water would be delivered to the headwaters of the Tualatin through an existing tunnel. All the added capacity would be allocated to municipal uses, including water for in-stream dilution to meet quality standards. Approval of the added Barney capacity must await an environmental impact assessment. Depending upon the allocation of the added capacity, the increased flow could contribute significantly to meeting the TMDL in the short run.

The expansion is estimated to cost $22 million and many of the costs have been incurred (i.e., sunk costs). Other costs are not expected to be large because the original project planned for this expansion, and infrastructure and land are already in place. Inundation of project land will diminish wildlife habitat and other former uses. Another implicit cost is the lost opportunities for in-stream uses of the water in the Trask River. Beneficiaries of the interbasin transfer are Tualatin River uses in the summer months, including recreationists, riverside residents, and others. There may be considerable political opposition to such an interbasin transfer, which implicitly suggests the Tualatin Basin cannot solve its water quality problems without importing external water.

ii) Reallocate Scoggins Reservoir capacity

The 53,000 acre feet of usable capacity in Hagg Lake is currently allocated as:

23,000 acre feet	Tualatin Valley Irrigation District
14,000 acre feet	Municipal uses
12,000 acre feet	Unified Sewerage Agency
4,000 acre feet	Other

Irrigation in the Tualatin Valley uses modern sprinkler technology for the most part. Current irrigation efficiency studies suggest irrigators can increase efficiency by small amounts without significant cost (e.g., through better scheduling). Large-scale savings in water use, or leasing water rights, would require changing cropping patterns and probably significant short-run costs. Reducing irrigation water by over 50 percent to gain the in-stream water quality effect would significantly decrease revenues, increase cost, require new capital investments (e.g., drip technology) plus changes in cropping patterns. Changing the timing of water releases to increase summer (July and August) flows would also require changes in irrigation practices, or foregone revenues.

The potential for reallocating municipal water to save reservoir capacity for in-stream water quality uses is uncertain. Because current water pricing schemes rarely charge the full opportunity cost of water, some social inefficiency is probably present. Reaching the water quality target through diverted municipal uses alone is not feasible. However, increased efficiency in the agricultural and municipal sectors coupled with diverted Trask River water could produce enough capacity at low cost. The Unified Sewerage Agency (USA) allocation is already used for pollution control purposes.

iii) Build new reservoir capacity in the Tualatin Basin

Another approach to increase summertime flows is to build new capacity dedicated largely to in-stream quality uses. The expansion of Scoggins Reservoir (by raising dam height 7-10 feet) or building new reservoirs on tributary streams are possibilities. Over 12,000 acre feet is necessary at present to increase the River's flow to a level consistent with the TMDL target. Costs of adding this new capacity include land purchase, construction, and other significant opportunity costs. Initial investment costs would likely fall in a range of $12-24 million. Because the water must remain in the river, revenues from irrigation and/or municipal uses can not be collected to offset the project costs. It has been difficult recently to justify new capacity either economically or politically, even with the sale of some capacity. New reservoir capacity in the Tualatin, perhaps costing $20 million, is probably no exception to this trend.

iv) **Transfer water from the Willamette River**

Water could be diverted near river mile 50 from the Willamette River to augment Tualatin River flows during the summer months. The costs of the diversion include construction and energy costs of pumping, plus the opportunity costs of the diverted water in the Willamette River between the diversion and the return at the Tualatin River outfall. These costs would be concentrated on the Willamette River users, probably riverside residents and recreationists, between the diversion and the outfall.

B. Decrease the Phosphorus Load

Phosphorus enters the Tualatin River from wastewater effluent, industrial sources, urban runoff, erosion and through leaching from soils and parent material via groundwater flows to streams. Point sources from municipal effluent have largely been controlled by the USA. Nonpoint sources from urban, agriculture and forestry activities entering through surface or groundwater are the remaining challenge. However, as evidence grows that groundwater concentrations of P exceed those in the River, the primary focus should shift to activities with the potential to decrease P that eventually flows through groundwater to the River. In contrast to flow augmentation measures, these source reduction measures attempt to reach concentration targets by lowering loads rather than diluting the existing concentrations with more water.

i) **Alter agricultural practices to reduce phosphorus delivery**

Based on recommended rates, farmers, ranchers, and horticulturists are estimated to apply up to approximately 14.5 million pounds of phosphorus fertilizer annually (average of 83 lbs/acre/year) in the Tualatin Basin. Some of the phosphate is used for crop growth, some runs off the surface attached to sediment or organic matter, some leaches to the groundwater and most of it is stored in the soil. Several measures are available to reduce phosphorus loads to streams, including:

* Applying phosphorus at lower rates.
* Incorporating broadcast applications of phosphorus or banding phosphorus applications.

* Applying manures and other wastes uniformly and at recommended rates to soils that are not water-saturated, followed by incorporation into the soil.

* Installation of clean water diversions and more efficient treatment and handling facilities in confined animal feeding operations.

* Reducing nursery runoff through better irrigation management, clean water diversions, and water reuse.

* Reducing erosion by conservation tillage, cover crops, mulches, and filter strips.

* Improving irrigation management, through new water distribution techniques and alternative application schedules.

A 20 percent reduction in phosphate fertilizer use was analyzed in the Resource Management Report, "Estimated Costs of Reducing Nonpoint Phosphorus Loads from Agricultural Land in the Tualatin Basin, Oregon" (Cross and Woods, 1994). Application of these practices to basin cropland is estimated to cost approximately $6.5 million per year on average, but could range significantly below or above that figure. In general, the short-run cost impact is greater, given opportunities for adjustment in the longer term. Much of the cost burden would probably fall on specialty, grain, berry, and fruit and nut production.

Phosphorus budgets for the River are not yet sufficiently precise to know how much comes from runoff or leaching through agricultural land. Indications from summer concentrations in the tributaries are that most of the phosphate comes in subsurface water. Phosphate applied to the soil surface reaches groundwater in tens of years. Changes in phosphate use contribute to long term solutions, but not to short term solutions.

ii) Control urban phosphorus applications and runoff

Urbanization recognized in comprehensive land use plans covers approximately 17 percent of the Tualatin Basin and is concentrated near the lower reaches of the River, the areas that experience excessive summertime algal blooms. Urbanization increases stormwater runoff volumes and peak flows, leading to additional scour and reduced baseflow, and contributes additional phosphorus loads and sediment to the River. Also, there can be illicit discharges, such as heavy metals, pesticides, and hydrocarbons. All of these urban pollution sources diminish water quality and degrade fish habitat.

Designated management agencies in the Basin have concentrated on urban "Best Management Practices" (BMPs). Those that could reduce phosphorus load deliveries to the Tualatin River include:

* Increase infiltration through land use planning by maximizing contact of runoff with pervious areas, e.g., through minimal use of curb and gutter construction.

* Construct stormwater detention and "wet" ponds for flood peak reduction, sedimentation, and phosphorus removal.

* Reduce loads through public education and physical means.

Costs of these measures vary depending on needs for land, volume of water treated, and personnel and equipment needs. Available data and modeling capacity permitted only an appraisal of the likely costs of constructing detention and "wet" ponds. Cost estimates range from about $4 to $7 million for establishing the practices.

Urban BMPs are commonly employed in new developments where the cost is borne by the developer. Cost of retrofitting existing developments with BMPs could be spread over all urban residents and water system users, a number currently exceeding several hundred thousand households in the Basin, possibly by means of a stormwater utility. Because the demands for improved water quality stem from downstream areas, the costs of control may be fully or partially offset by increased benefits to local citizens.

iii) Control forest practices that deliver phosphorus

Nearly half of the Tualatin Basin is in forest cover. Nonpoint source pollution from forest land management is controlled by Oregon's Forest Practices Act. Evidence from lack of rules violations and from stream monitoring data suggests that forestry activities are not a major factor in augmenting phosphorus delivery to the River. There may be local situations, in urban and rural areas where forestry operations cause unnecessary water quality damage. Application of Forest Practices Rules to these areas would reduce surface runoff and erosion.

Costs of the measures vary widely, in part due to varying forest and land conditions in the Basin. As with agricultural practices, the short-run cost adjustments would be considerably larger than long-term costs, where new procedures and technology lessen the effects of practice restrictions. No formal modeling analysis was conducted of these practices, given the minor perceived role of forestry in river water quality problems.

iv) Reduce wintertime phosphorus point source loads

Though summertime phosphorus concentrations are the water quality target, wintertime loadings may be depositing phosphorus onto sediments or other stream bottom materials and releasing the phosphorus during the subsequent low flow summertime condition. During summer months, removal of phosphorus from the sewage treatment plan effluent has the potential of reducing the total phosphorus load by over seventy percent. During the winter months, however, due to the greater stream flow, increased erosion and greater runoff from urban sources, the fraction of phosphorus from the wastewater treatment plans falls to between 20 and 50 percent depending upon recent rainfall patterns. Thus, in addition to high costs of operating a biological process during the winter, there is little evidence to suggest that wintertime phosphorus removal would reduce the summertime phosphorus concentrations in the Tualatin pool area.

C. Stream Corridor Modification

A healthy watershed is a cohesive ecosystem including tributaries, mainstem, and the in-stream environment with adjacent riparian zones and floodplains. The Tualatin River ecosystem has been affected by extensive land use changes to urban and agriculture over the past century. Alterations on the landscape and in the stream affect phosphorus delivery and retention via riparian zones, habitat availability for biota within the stream and along the shore and biological productivity within these interacting zones.

Three measures could enhance stream function and aquatic health:

* Lower the Lake Oswego dam to restore natural hydrology
* Restore riparian zones
* Restore and develop wetlands

The dam at Lake Oswego raises the river level by 3 to 4 feet and holds water and phosphorus for longer periods in the lower quiescent stretches. Lowering the dam would add costs of pumping into Lake Oswego. Precise estimates of these costs are not available. Lowering river levels 3 to 4 feet would decrease riverside property values initially; however, landowners would benefit from increased floodplain lands along the River that would be re-vegetated naturally within a few years. Recreational values may change, possibly limiting boating in some areas, but enhancing nature watching activities not only in the areas adjoining the diversion dam, but also downstream where little water flows in the summer at present. Short-term costs of this measure would be concentrated on riverside landowners, boating recreationists, and those paying the pumping costs. In the long-term, added value to riverside properties, increased survival of salmonid fishes migrating through the mainstem and improved crayfish fisheries would offset some of the costs.

Restoration of vegetation in riparian zones would increase the interception of surface water runoff carrying sediment and/or phosphorus. Riparian vegetation would also intercept phosphorus in subsurface flow. Riparian vegetation and soils would hold wintertime rains for infiltration, increasing bank storage and augment summer recharge of the River. Where riparian canopy covers the channels of tributaries, temperatures could be reduced through shading effects.

Because of cumulative effects accruing downstream, riparian restoration in tributaries probably would provide improved water quality down stream more quickly than major efforts on the mainstem. Gales Creek, one of two creeks identified by the Oregon Department of Fish and Wildlife for restoring wild runs of cutthroat trout, is a good candidate for restoration of riparian canopy. Where riparian areas are developed for agriculture, riparian restoration can be a joint effort with local, state, and federal programs. The limited extent of development on Gales Creek suggests that restoration there would be more economical than in more developed areas. A preliminary assessment indicates expenses in the neighborhood of approximately $95,000 for restorable riparian lands along Gales Creek. Some type of trading regime in which urban development that degrades riparian habitat would purchase rural riparian habitat restoration may be feasible to generate financing.

Dairy Creek has also been targeted for restoration of cutthroat trout. Riparian vegetation on McKay and Dairy Creeks would provide badly needed filters for sediment and nutrient loads off the landscape. Satellite imagery indicates scarce riparian protection at present. The preliminary analysis suggests approximate costs of about $270,000 for restorable riparian areas along the west Fork of Dairy Creek.

Where riparian areas are in agricultural uses, conservation easements could be purchased that permit compatible uses while protecting riparian vegetation. In extreme situations, reestablishing riparian zones may require full land purchase. Fewer additional costs may be required in forested reaches because of guidelines for riparian areas in state and private forested lands. In urban areas along tributaries and on the mainstem, planting of riparian vegetation and reduction of chemical use should be encouraged through education and public cost sharing.

Restoration of more wetlands in the Tualatin Basin would provide natural filters for runoff waters carrying sediment and phosphorus to tributaries and the mainstem. High priority might be given to the river section between Forest Grove and Jackson Bottom, where floodplain restoration is occurring. The lands are less developed than further downstream, and a value for wetlands has been established. The addition of wetland function in these areas would improve connectivity to Jackson Bottom and the Hillsboro landfill; these recently restored wetlands would provide excellent colonizing populations of birds and wildlife. Recreation values including nature watching and hiking can be expanded into newly acquired lands, increasing the associated tourist industry in the Basin. As with riparian areas, wetlands would require full purchase or conservation easements.

D. Change In-Stream Processes

Phosphorus concentrations, flow levels, and temperature combine to produce the undesirable algal growth. *In-situ* mixing of water strata could reduce the conditions promoting excessive algal growth.

A device similar to a sub-surface waste diffuser directed latitudinally across the River could be used. The water mixing would promote oxygen transfer, thus increasing dissolved oxygen, maintaining aerobic conditions to reduce phosphorus and other nutrient recycling and reduction of odors. The construction costs for each unit would be in the order of $150,000 with annual operating costs in the order of $20,000 per year assuming four months of operation. The number of units required is not known.

E. Continue Current Pollution Control Strategies

Another approach to the water quality problems in the Tualatin Basin is to continue to pursue present pollution load reduction strategies. Various Designated Management Agencies in the Tualatin Basin have developed and implemented plans to protect water quality. This approach has been successful in avoiding a water quality problem of drastic proportions that would otherwise have occurred. Had not the major segments of the Basin actively pursued load reductions, the Tualatin River would by now have had periods of absolute oxygen depletion during the summer months and algal blooms far more severe than have occurred. Having had the USA constructing phosphorus removal facilities has avoided more severe water quality problems. Although these efforts have not improved the aesthetic quality of the River, they have prevented more drastic water quality limitations.

Among the steps required to pursue this strategy are:

* Continue to practice phosphorus removal from the sewage treatment plants.

* Actively pursue nonpoint pollution control strategies through BMPs in the agricultural, forestry, and urban portions of the Basin.

* Promote and encourage compliance with Confined Animal Feeding Operation rules and regulations to the maximum extent possible.

While continuing in this way for another few years may avoid significant deterioration, it will not achieve significant improvement.

APPLICABILITY TO OTHER RIVER BASINS

It is important to know whether the methodology developed for analysis and evaluation of Tualatin River Basin water quality is transferable to other Oregon river basins with similar water quality limitations and pollution problems. Among various concerns is the practical question of being able to extend the utility of the investments made in modeling and decision-making tools.

This section of the report provides an appraisal of the ways in which the developed evaluation tools can be applied to other similar basins. Appraisal is also made of the effort needed to adapt the evaluation tool and of the likely success in achieving a transferred product.

1. Transferability of Methodology

The analysis and evaluation process relied on both conceptualization and computer modeling. Conceptualization involved the development of ideas and concepts to understand and explain water quality conditions in the Tualatin Basin. It also involved the evaluation and testing of those ideas against available data. Computer modeling involved the logical manipulation of information to produce a description of the system. However, the computer modeling also required a very great amount of conceptualization, separate from the broad conceptualization in development of ideas.

Conceptualization was carried out as a collective activity of the entire research team, led by various individuals, to better understand the existing system, the failures of past efforts at water quality management, and the alternatives that might be tested for making improvements. To do this successfully, it was essential that interaction occurred with the computer model.

Computer modeling was led by two individuals and guided by several others in the research team. Emphasis was placed on developing the means for producing numerical information that could be used to extend the conceptualization efforts. Computer models, being "tools," must be handled in appropriate ways if they are to be useful. Deciding how this handling could best be done was the creative task of the team's modelers. Even though the models used were general models with a "track record" of having been used elsewhere, a great deal of effort was required to make them responsive to the demands of the team for testing alternative scenarios to improve water quality.

In terms of importance, the conceptualization phase is absolutely essential for any serious analysis of water quality problems in a river basin. Many of the water quality problems that still persist suffer from a lack of sufficient conceptualization to truly understand the roots of the problems.

The computer modeling phase is actually an extension of the conceptualization phase. The main advantage of computer models over conceptual models is that they can manipulate and integrate large amounts of complex physical and chemical data and produce numerical results, whereas the brain of the conceptualizer can use the same approach but is unable to develop the precise numerical values. Surprisingly, good conceptualization often produces good "order-of-magnitude" estimates that the computer model then refines by replacing some of the zeros with nonzeros.

2. Transferability of Findings

The problems of the Tualatin River are not shared by all streams in Oregon. A few other river basins in the State, such as the Yamhill Creek and Bear Creek also have disproportionate shares of the summertime river flow impacted by return flows and treated effluent. Many developed basins, such as the Willamette as a whole or the Sandy, have ample high-quality streamflow originating from headwater sources. Therefore, the numerical findings for the Tualatin River may apply directly only to a few other basins, except perhaps as an indicator of how bad conditions can become if efforts are not made early to address the control of contamination of surface waters and interconnected subsurface waters.

The alternative solutions proposed for the Tualatin, on the other hand, are underlain by general principles that have broad applicability. The ability to control nutrients and contaminants in a river requires basic understanding of the processes involved and the stream ecosystem impacted, together with ideas for using the natural system to advantage. Technology has an important role, whether through wastewater treatment, control of the flow of potential contaminants during their use for other purposes (e.g., fertilizers), or manipulation of water stored in reservoirs.

Therefore, our evaluation suggests that the findings are transferable. They are applicable in the sense that they are the kinds of solutions that may be considered elsewhere, even if they are not transferable.

RECOMMENDED ACTIONS

The water quality problems of the Tualatin Basin are complex and have resulted from a variety of developmental activities spanning decades. The point sources of pollutants have been brought under control, yet the streams of the area do not meet current water quality criteria. No single measure or additional treatment strategy will solve what is a complex watershed problem. In order to restore the Tualatin and its tributaries, a series of coordinated programs will be required.

1. Continue Aggressive Nonpoint Source Load Management Programs

Recent activities within the Basin have been to manage and reduce the phosphorus loads entering the Tualatin River from a variety of sources. These measures will need to be continued for the foreseeable future. They include compliance with pollution control measures for both cropland and animal agriculture. Further research may support restricting the application of phosphorus to cropland so that application more nearly matches the crop removal rate. The current practice of removing phosphorus from the sewage discharged into the River is essential. Measures also include ecologically-oriented forestry practices and aggressive adoption and implementation of the best urban nonpoint pollution control measures. Appropriate planning of future development to minimize water quality impacts is also critical.

2. Intensify and Expand Public Involvement in a Long-Term Planning Process

Water quality monitoring in the Tualatin Basin has established that recent trends in changing land uses exceed the ability of the Tualatin River to accommodate the nutrient load. Growth of algae at levels incompatible with established water quality criteria results. Restoration of the Tualatin Basin is a major public decision. It involves dramatic decisions concerning land use and planning for economic development. This requires public involvement. Decisions of this magnitude are not made quickly nor without intensive study. It is appropriate to expand and intensify that process.

3. Establish a Source of Supplemental Stream Flow

Recent experience and application of the models to the watershed has demonstrated that phosphorus load management is not sufficient to attain the quality of the Tualatin that meets the established water quality criteria. The least expensive way to achieve that quality over the short to intermediate term is to provide additional water storage sufficient to provide a minimum of 100 cfs of additional supplemental flow during July and August. Under the current conditions, storage of water in the Trask Basin offers the least expensive source of this supplemental water.

Flow augmentation is needed as a short-term solution to achieve a stable level with present pollution loads. But it is not a long-term solution because it will always lag behind the increasing needs. Source reduction, through various alternatives discussed in this report, is required.

Source reduction needs to be tied specifically to increased needs, e.g., so many more acres of wetland for each square mile of urban subdivision, or so many miles of riparian vegetation for each increase in intensity of agricultural use. Our present mode is to decrease wetlands as we convert more land to impervious surfaces for urban uses, and decrease riparian vegetation with increased intensity of agricultural land use. Making no change will continue to aggravate the problem.

An alternative to storing water behind structures such as dams is to store more water in the landscape. This serves the same function of releasing water later during the summer. Wetlands along the River are one component of this. Managing agricultural lands for maximum infiltration is another component, and land use planning for maximum pervious surfaces in urban areas is another. The amount of pervious surface and the distribution of pervious surfaces within the urban landscape determine the amount of infiltration vs. the amount of immediate runoff. This has implications for both quantity and quality of water.

4. Restore Wetlands and Riparian Areas

Both phosphorus removal and increased summer flows of water can be achieved by wetlands. Wetlands store water during high-flow periods for later release into the River. Wetlands function as sinks for nutrient removal from water. Riparian vegetation traps sediment and prevents phosphorus absorbed to sediments from reaching streams during periods of overland flow. The roots of riparian vegetation also take up phosphorus that is moving to the streams from interflow or from baseflow.

5. Manage the River for Biological Communities

Different components of the biota have different environmental requirements, for example temperature. One of the uses of the lower stem Tualatin now is for sports fishing of warm water fish species. Encouragement of warm water species by providing the conditions they require discourages cold water species such as the anadromous fish. Decisions must be made as to which fish communities to encourage at which points in the Basin.

WORKING PAPER REPORTS

The detailed studies on which this summary report is based are published in the series, "Tualatin River Basin Water Resources Management Reports." Copies are available from the Oregon Department of Environmental Quality, Portland, Oregon or the Oregon Water Resources Research Institute at Oregon State University, Corvallis, Oregon.

Published Reports

Report 1 — Wolf, D. W. Land Use and Nonpoint Phosphorus Pollution in the Tualatin Basin, Oregon: A Literature Review.

Report 2. — Miner, J. R. and E. F. Scott. An Analysis of Water Quality Data in Tualatin River Tributaries with Three Different Land Uses.

Report 3. — Wells, S. A., C. Burger, and M. Knutson. Modeling the Tualatin River System Including Scoggins Creek and Hagg Lake: Model Description, Geometry, and Forcing Data.

Report 4. — Miner, J. R., P. O. Nelson, and S. Vedanayagam. Late Winter 1992 Sampling for Water Quality in Three Stream Segments of the Tualatin River Basin, Oregon.

Report 5. — Miner, J. R. and E. F. Scott. Data Analysis: Water Quality of Dairy Creek and Major Tributaries.

Report 6. — Shively, D. D. Landscape Change in the Tualatin Basin Following Euro-American Settlement.

Report 7. — Cass, P. L. and J. R. Miner. The Historical Tualatin River Basin.

Report 8. — Li, J. and S. V. Gregory. Issues Surrounding the Biota of the Tualatin River Basin.

Report 9. — Cross, T. L. and M. Wood. Estimated Costs of Reducing Nonpoint Phosphorus Loads from Agricultural Land in the Tualatin Basin, Oregon.

Report 10. — Knoder, E. Benefits and Costs of Riparian Habitat Improvement in the Tualatin Basin.

Report 11. — Ervin, D.E. Analysis of Pollution Control Strategies for the Tualatin River.

Report 12. — Miner, J. R. Response to Comments From Public Hearings.

Report 13. S. Vedanayagam and Nelson, P. O. Mass Balance Analysis of Suspended Solids in the Tualatin River.

Report 14. S. Khaodhiar and P. O. Nelson. Summary and Assessment of Toxics Data for the Tualatin River.

Report 15. E. F. Scott, M. Wood, and B. P. Warkentin. Agricultural Land Use In the Tualatin Basin.

Report 16. Taylor, G. H., J. R. Miner, and P. C. Klingeman. Estimating the Frequency and Quantity of Surface Runoff Within the Tualatin Basin.

Interim Report. A Project to Collect Data and Provide Evaluation and Recommendations for Alternative Pollution Control Strategies for the Tualatin River Basin, March, 1993.

Final Report. Evaluation of Alternative Pollution Control Strategies for the Tualatin River Basin, Oregon.

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Berger, C. Water Quality Modeling of the Tualatin River. (1994) Portland State University, Portland, OR. (also Technical Report #EWR-01-94).

Knutson, M. Modeling of Flow and Water Quality in Hagg Lake near Forest Grove, Oregon. Portland State University, Portland, OR. (also Technical Report #EWR-04-93).

Tang, F. Calibration and Verification of HSPF Model for Tualatin River Basin Water Quality. (1993). Portland State University, Portland, OR.

Wolf, D. W. Land Use and Nonpoint Source Phosphorus Pollution in the Dairy-McKay Hydrologic Unit Area of the Tualatin River Basin, Oregon. (1993). Oregon State University, Corvallis, OR.