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Socioeconomic Environmental Studies Series

RESTORING THE WILLAMETTE RIVER:
Costs and Impacts of Water Quality Control

Environmental Research Laboratory
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RESTORING THE WILLAMETTE RIVER:

COSTS AND IMPACTS OF WATER QUALITY CONTROL

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ABSTRACT

The means by which the water quality of the Willamette River has been upgraded over the past four decades are documented. Two strategies --point-source wastewater treatment and flow augmentation from a network of federal reservoirs--have been responsible for this improvement in water quality. The series of tactics employed in gradually reducing point-source waste discharges are documented. Coincident water quality benefits which have resulted from flow augmentation for other purposes are also discussed.

The economic and energetic costs of constructing, operating, and maintaining the facilities which have significantly contributed to the improvement of water quality in the Willamette River and its tributaries over the last half century are examined. Data are presented regarding the construction and operation of municipal collection and treatment systems, industrial water pollution abatement facilities, and reservoirs. Input-Output economics and a methodology for converting dollar costs to direct and total energy requirements are used to deal with construction and operational costs. Operation and maintenance expenditures are also dealt with on the basis of direct at-site requirements. Energy needs for operating water quality control facilities are about one-tenth of one percent of total basin energy utilization. Substantial savings of this energy are possible, however.

Historic and current status of the fishery and wildlife resources of the Willamette River Basin are reviewed in relation to changing water quality of the River. Recent improvements in water quality have stimulated State and Federal agencies to embark on a nine-year program to fully develop the fishery resources of the Basin. The potential biologic, economic, and social values of the program are presented along with related adverse effects attributed to water quality improvement procedures.

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SECTION I

CONCLUSIONS

1. Two pollution control strategies are essential to maintain the water quality of the Willamette River. First, at-source wastewater treatment must be required at a level sufficient to keep the absolute pollutant loading of the river within limits that will allow the meeting of water quality standards. Second, flow augmentation is required to provide a sufficient volume and depth of water to maintain desirable waste dilution, stream temperatures, and dissolved oxygen concentrations.

2. Future population growth and/or industrial expansion that generate additional wastes will unbalance the present water quality status. Thus, higher levels of wastewater treatment, greater augmentation flows from upstream reservoirs, or some combination of these measures will be required. Many possibilities for altering wastewater treatment levels are available as many of the industries which have contributed the largest pollution loads (e.g., pulp-and-paper mills) have independent wastewater treatment facilities and several others (e.g., food processors) could provide various measures of pre-treatment or could separately treat and dispose of wastes which now enter municipal systems (as already done to a limited extent). The possibility also exists for greater flow augmentation from existing impoundments (at the cost of reducing other reservoir benefits) or from impoundments constructed in the future.

3. Very few data exist regarding the energy costs of goods and services. The ability to accurately evaluate the total energy commitment associated with the improvement of water quality in the Willamette Basin is therefore limited.

4. Capital energetic costs are important factors in the consideration of total annual project costs. The total capital energies (at-site construction energy requirements plus the energy required to produce the materials and equipment incorporated in the finished product) of a treatment facility can exceed the facility's lifetime operational energy requirements.

5. In estimating the energy costs of constructing water pollution control facilities in the Willamette Basin, less than 10 percent of the total is reflected in the direct on-site needs of a constructor. Much energy is embodied in the materials and process equipment which are required for any project. This is particularly true of wastewater treatment facilities. Thus an estimate of the direct construction energy requirements is not a sufficient measure upon which to judge the total energy impact of building a facility.

6. Electricity used in operating and maintaining water quality control facilities represents about 480 Tera Joules (TJ) (140×10^6 kilo-Watt·hours (kW·hr)), or nearly seven-tenths of one percent of the total electrical needs of the Willamette Basin. Large energy savings could be made by properly designing collection and treatment systems or by relying more heavily upon nature's assimilative capacities.

7. Wastewater lift station costs, particularly energy expenditures, are important considerations in municipal wastewater control. Pumping of municipal wastewaters in the Willamette Basin consumes about 25 percent of the energy used in collecting and treating these flows. Some Willamette Valley cities use more energy pumping flows than in treating them.

8. Post chlorination of municipal wastewater requires large inputs of energy. The energy required to produce the chlorine used for this purpose is equal to between 40 and 50 percent of the electrical requirements of operating all the municipal treatment facilities in the Willamette Basin. However, over-application accounts for a large portion of this value and a large savings of resources could be realized by proper surveillance of this practice.

9. Low flow augmentation by the federal reservoir system plays an important part in the water quality management picture of the Willamette Basin. The water quality control portion of the reservoir costs, briefly estimated, is equal to less than 10 percent of the capital and one percent of the operational investments made by municipalities and industries combined.

10. In the past, poor water quality has impeded full development of the fishery and recreational resources of the Willamette River Basin. Maintenance or continued improvement of current water quality standards are a necessary element in the goal of producing an additional 180,900 salmon and steelhead worth in excess of $2,398,000 annually. Other recreational and aesthetic resources of the River benefit from water quality improvements. The aesthetic and biologic costs of wastewater treatment activities seem minor compared with overall benefits.

SECTION II

RECOMMENDATIONS

1. Due to the overlapping of tactics, it was not possible to separately assess the impact of each pollution control technology applied to wastewater treatment using actual water quality data obtained for the Willamette River. The separate influences of different wastewater treatment technologies can be estimated by use of the recently developed U. S. Geological Survey's Willamette River water quality simulation model. The water quality associated with each tactic and its corresponding pollutant loadings should be evaluated using this model.

2. Flow augmentation was found to have a highly significant influence over summer-autumn water quality in the Willamette River. However, the actual augmented flows varied irregularly and were generally greater than target flows at control points along the Willamette. The effects of flow augmentation need to be investigated in a more systematic manner than from historic data alone. By use of the U. S. Geological Survey's water quality simulation model, various levels of flow augmentation can be studied for their influence on river water quality. This should be done in conjunction with the simulation of different wastewater treatment tactics in order to more fully explore alternative means of pollution control.

3. Energy analysis, the association of energy values with various goods and services, requires a definite commitment of research effort in the future. In the construction industry this might include close surveillance of on-site energy needs for various activities.

4. Increased investigation of wastewater treatment operational parameters should be undertaken. This work should focus on other than mainline treatment. For example, sludge handling and disposal are becoming increasingly important; but relatively little, other than pilot plant and demonstration facility data, is known about the costs and benefits of this treatment.

5. Chlorine application should be researched in depth and closely monitored by regulatory agencies. Chlorine production is highly energy intensive and a substantial reduction in its use would yield significant energy savings. This fact, along with chlorine's counter-productive in-stream biological effects and possible carcinogenicity, clearly shows the need for further research. This work should include evaluating the need for bacterial reduction as well as evaluating alternative means by which this reduction might occur.

6. A comprehensive look at wastewater collection and treatment, as they relate to each other and as they relate to other factors such as transportation, land use, and air quality, is needed. For example, large regional treatment facilities requiring long interceptor lines and pumping of flows should be carefully evaluated. While economies of scale may be realized in the treatment end of this work, the resource allocation for the total system could be greater than that required for an alternative system of several smaller, local plants.

7. Further research of cost allocation in multi-purpose projects such as reservoirs is needed. This work should include the evaluation of negative impacts as well as normally considered benefits and should not be limited to solely economic considerations.

SECTION III

INTRODUCTION

BACKGROUND

The Willamette River during the first half of the twentieth century was described as a "stinking", "ugly" and "filthy" river--an "open sewer" of untreated sewage and wastes. At times the condition of the Willamette was so "intolerable" that workmen even refused to work on river-side construction near sewer outfalls.[1] Portland citizens spearheaded efforts to bring the deplorable state of the river to the attention of city, county and state officials. But little or no response resulted. The worsening situation, documented by water quality tests conducted by the Oregon State Board of Health and concern expressed by the U. S. Public Health Service, only slowly made inroads on legislative inertia. Additional support from public groups and the League of Municipalities, backed with further data from surveys by the Engineering Experiment Station (Oregon State University (OSU)--then Oregon Agricultural College), Oregon State Board of Health (OSBH), and Oregon Fish and Game Commission, drew administrative response from the Governor's office, but still no effective legislative action. Finally, in the face of continued inertia from the State Legislature, the citizens of Oregon passed an initiative measure in November, 1938, by a resounding majority vote, to create the Oregon State Sanitary Authority (OSSA).

The period from 1939, and especially since the end of World War II, until the end of the 1960's is one of increasing determination and accomplishment in abating the pollution of the Willamette River.

Today, because of an aroused citizenry and concerted efforts by local, state and federal groups, the Willamette River meets demanding water quality standards throughout its length. It stands out nationally as an example of a "river returned", a "new river". Although not pristine, the Willamette River has been restored to a cleanliness unknown since the last century--probably close to that encountered by early white settlers.

The Willamette River of today offers a broader spectrum of recreational and scenic opportunities for the people of Oregon than it has known for several decades. Granted that technological development makes possible many types of recreation unknown to our forefathers, the fact remains that for over half a century the river was too badly polluted along many parts of its length to encourage swimming, boating, hunting, fishing, or even viewing--all of which are today enjoyable in those same locations. Plans and programs for river-related activities, such as the Willamette Greenway concept throughout the Willamette Valley or the Johns Landing urban redevelopment near downtown Portland, can at last be predicated upon the high water quality of the Willamette River.

There have been significant benefits of cleaning up the Willamette River to both Oregonians and the nation. The example offered by the Willamette may be repeatable elsewhere in similar basins in efforts to provide "quality" environments. But the costs of retrieving a "nearly lost" river are also great and these too must be considered and evaluated. Expenditures of large magnitude had to be made in money, manpower, materials and energy in order to return the river to its present desirable condition. Such expenditures continue year after year so that the quality of the river may be maintained and improved. The benefits of pollution abatement have been described in many ways to the public; hence programs of pollution control have strong citizen support. The direct, obvious costs of water quality protection, such as the costs of pollution control facilities, are generally known. But pollution control has less-direct, less-obvious costs which must also be known. For example, a network of flood control reservoirs provide substantial water quality benefits through the conservation releases made during the non-flood season; these benefits are not really free but are inherent in the costs of constructing, operating and maintaining these facilities. Similarly, the removal of wastes from municipal and industrial sewage treatment systems before effluents enter the Willamette River or its tributaries is accomplished at the cost of producing equipment and chemicals (and pollution) elsewhere for use in these treatment systems and at the cost of producing pollutants at these treatment systems that are disposed of onto land or into the atmosphere. Realistic evaluation of water pollution abatement must include benefits and costs which extend beyond the waters of the Willamette River and its tributaries and the waste treatment plants which line their banks. From a broader perspective, a clearer picture emerges of the true benefits, costs and impacts of water quality improvement for a river basin.

The 1970's have fast become an "energy-conscious" decade. Energy problems faced by the nation have led us, as never before, to evaluate the energy costs of doing things. Pollution control facilities of all types require considerable expenditures of energy for their construction, operation, maintenance, expansion, and modernization. The Willamette River "clean-up", therefore, has required the use of a gread deal of energy. But, hithertofore, no study has been made of the magnitude of such an energy expenditure to abate pollution in the Willamette River Basin, or, for that matter, any other river basin.

This report addresses the question of energy expenditures required to restore the water quality of the Willamette River. The energy costs are described and documented to that extent possible during the study period with available information and the analyses made therefrom. Hopefully, the results reported and conclusions drawn will help fill a significant gap in the broad-perspective picture needed for water quality improvement in a river basin.

PURPOSE OF STUDY

The purpose of the study reported here has been to describe and document, insofar as possible, the energy costs of the pollution control techniques that have been used to restore the water quality of a river basin. The Willamette River is used because it is one of the largest rivers in the United States (ranking 12th in size) where a highly significant restoration of water quality has been accomplished. Documentation of the clean-up is excellent and thus a meaningful analysis can be attempted. The energy requirements of an undertaking such as cleaning up a river can in many respects be determined from study of the economic costs of the required facilities. Coupled with economic costs and energy expenditures are a variety of environmental impacts. Further, the accomplishment of pollution control itself produces many environmental impacts. Therefore, in treating the subject of energy costs of pollution control, it is necessary to determine economic costs. Furthermore, it is important to address the environmental impacts in order to provide a measure for the justification of economic and energy expenditures in river clean up.

Four objectives have been pursued to fulfill the study goal. These objectives are:

1. To document the pollution control strategy that has been employed to date in improving the water quality of the Willamette River and to determine the contribution each control technology has made to the improvement of water quality;

2. To determine the total costs and annualized costs of construction and operation and maintenance for the pollution control facilities that have been employed in the Willamette Valley;

3. To determine the total energy consumed by all of the pollution control facilities that have contributed to the improvement of water quality in the Willamette River, including energy costs of constructing and operating dams (where appropriate) as well as treatment facilities and control devices; and

4. To determine the cumulative environmental impact of utilizing the pollution control strategy employed in the Willamette Basin.

SCOPE

The study included and was limited geographically to the Willamette River Basin. The time frame for the study extended from the early 1900's through 1974. During this time, the Willamette River experienced first a period of declining river quality accompanied by no attempts at pollution abatement, then a period of organization to confront the pollution problem, and finally a period of restoration of river quality. By 1972, the present degree of restoration of river quality had been virtually achieved. In the following two years the principal efforts have been aimed more at the maintenance of river quality, through improved monitoring, surveillance and enforcement, than at greater degrees of restoration. However, future strategies to fulfill stated national water quality goals appear to be in the offering, and the present thus provides a benchmark for surveying what has been accomplished and the cost of accomplishment in anticipation and preparation for the future.

The choice of the Willamette Basin for such a study is important for several reasons. First, the river exhibits a history of decline and near-total restoration of water quality. Second, there exists support documentation regarding input pollution loads, river flow conditions, and river quality over a long period of time. Third, the basin is large and complex, yet manageable, so that lessons learned from it will find applications to many other basins. Fourth, no one has documented in an integrated manner the economic, energetic and environmental costs of the water quality improvement program. Fifth, the Willamette is one of the largest rivers in the United States where such a dramatic increase in water quality has occurred throughout the river system. Sixth, because of the successful clean-up of the river, much national interest and attention has been focused on the Willamette Basin in recent years. And, finally, Oregonians collectively appear at the forefront as regards many environmental concerns; therefore, the measures, costs and benefits which the people have demanded or accepted to abate water pollution are instructional in considering similar efforts elsewhere.

In fulfilling the objectives stated above, limitations were set as to what types of facilities would be investigated as well as the kinds of expenditures for each facility. The economic and energetic costs of designing, constructing, operating, and maintaining portions of municipal wastewater collection and treatment systems, selected industrial water pollution abatement facilities, and federal reservoirs were researched. Municipal collection was limited to that portion of the system designated as interceptor. The research of industrial expenditures was limited to larger companies having self-operated treatment facilities. Reservoir research excluded those operated by private industry and utilities.

STUDY APPROACH

The nature of this study has demanded considerable knowledge of the behavior of the Willamette River, including its hydrology, its quality, and the aquatic life it supports. In some respects, the river serves primarily as a transportation and conveyance system. Yet the river system is a habitat for an abundant aquatic life and serves as a recreational playground for many of the 1.4 million Oregonians who reside in the basin. Consequently, the study had to be approached from several perspectives.

The study team included three faculty members and a research engineer supported by graduate and undergraduate research assistants. Peter C. Klingeman, Associate Professor of Civil Engineering, a water resources engineer with a background in hydrology and hydraulic engineering, led the study. Working with him was E. Scott Huff, a research civil engineer with a Master of Science in Sanitary Engineering. Herbert H. Stoevener, Professor of Agricultural and Resource Economics, and Howard F. Horton, Professor of Fisheries, both participated in the study from their broad backgrounds in environmental impacts of human activities on water resource systems and their specific, extensive backgrounds in natural resource economics and aquatic ecosystems, respectively. Support was provided by Kenneth A. Hanson, graduate research assistant in Agricultural and Resource Economics, and Charles B. McConnell and Darrel Gray, graduate students in Fisheries. Frank D. Schaumburg, Associate Professor of Civil Engineering, was a consultant to the study, contributing from an extensive background in sanitary and environmental engineering. Richard J. Heggen, Instructor in Civil Engineering, provided considerable technical assistance to the project in data evaluation and computer services, including the evaluation of water management computer programs for the Willamette River. Eugene A. Gravel, undergraduate student in Civil Engineering Technology with several years of construction experience, contributed in the evaluation of resource expenditures involved in construction activities.

The work conducted under objective 1 was based on examination and analysis of historical descriptive material and data contained in several reports and agency documents. Responsibility for this phase of the study was held by Klingeman and Huff.

The study activities necessary to meet objectives 2 and 3 involved extensive analysis and interpretation of construction, operation, and maintenance records for wastewater control facilities and dams. Methods had to be devised in many instances in order to extend data from such records into forms usable to describe dollar costs and energy costs. Responsibility for the work was held by Huff, Stoevener, and Klingeman.

The direct environmental impacts resulting from pollution control in the Willamette River were determined under objective 4 with greatest attention given to the impact of changed water quality caused by waste treatment facilities and supporting attention given to the impact of changed hydrologic regimen of the river due to regulation by upstream reservoirs. Horton bore principal responsibility for documenting most of the work carried out under this objective, with support from Huff and Klingeman.

SECTION IV

THE WILLAMETTE BASIN STUDY AREA

GEOGRAPHICAL FEATURES

The Willamette River Basin, shown in Figure 1, encompasses an area of Western Oregon of 29,676 square kilometers (km^2) (11,463 square miles (mi^2)).[2] The basin is approximately rectangular, but in the shape of an arrowhead 240 kilometers (km) (150 miles (mi)) long by 120 km (75 mi) wide. The valley lies between the Coast Range, to the west, and the Cascade Range, to the east. The two ranges extend southward to converge at the Calapooya Mountains and extend northward to the Columbia River. The Willamette Valley may be described in geological terms as a structural depression or downwarp with hills of moderate relief in places separating broad alluvial flats.[3] The valley floor consists of lake deposits and other consolidated and unconsolidated alluvium and covers about 9100 km^2 (3500 mi^2) with limiting dimensions of 200 km (125 mi) by 50 km (30 mi). Alluvial fans along the edges of the valley extend from the volcanic and sedimentary formations which comprise the surrounding mountains. Basin elevations range from 3 meters (m) (10 ft (ft)) mean sea level (msl), along the Columbia River to 120 m (400 ft) on the valley floor at Eugene to 1200 m (4000 ft) in the Coast Range and above 3000 m (10,000 ft) in the Cascade Range.

The Willamette River drainage system is shown in Figure 1. Formed by the confluence of the Middle and Coast Forks near Eugene, the river has a general northward course. Numerous tributaries enter from both the Coast Range and the Cascade Range. The streams from the west side of the basin have considerably smaller drainage areas and less-sustained summer flows than those originating in the Cascade Range. The Willamette River and its main tributaries (in their lower reaches) have broad floodplains and meander belts. Meandering diminishes in the northern part of the basin where the rivers are somewhat more confined by adjacent topography. The main stem includes short riffles, long deep pools, the falls at Oregon City, and a tidal reach between the falls and the mouth.

BASIN CLIMATE

The Willamette Basin climate is characterized by warm, dry summers and mild, wet winters. The nearby Pacific Ocean dominates the weather pattern whereas the Coast Range, Columbia River Gorge and Cascade Range

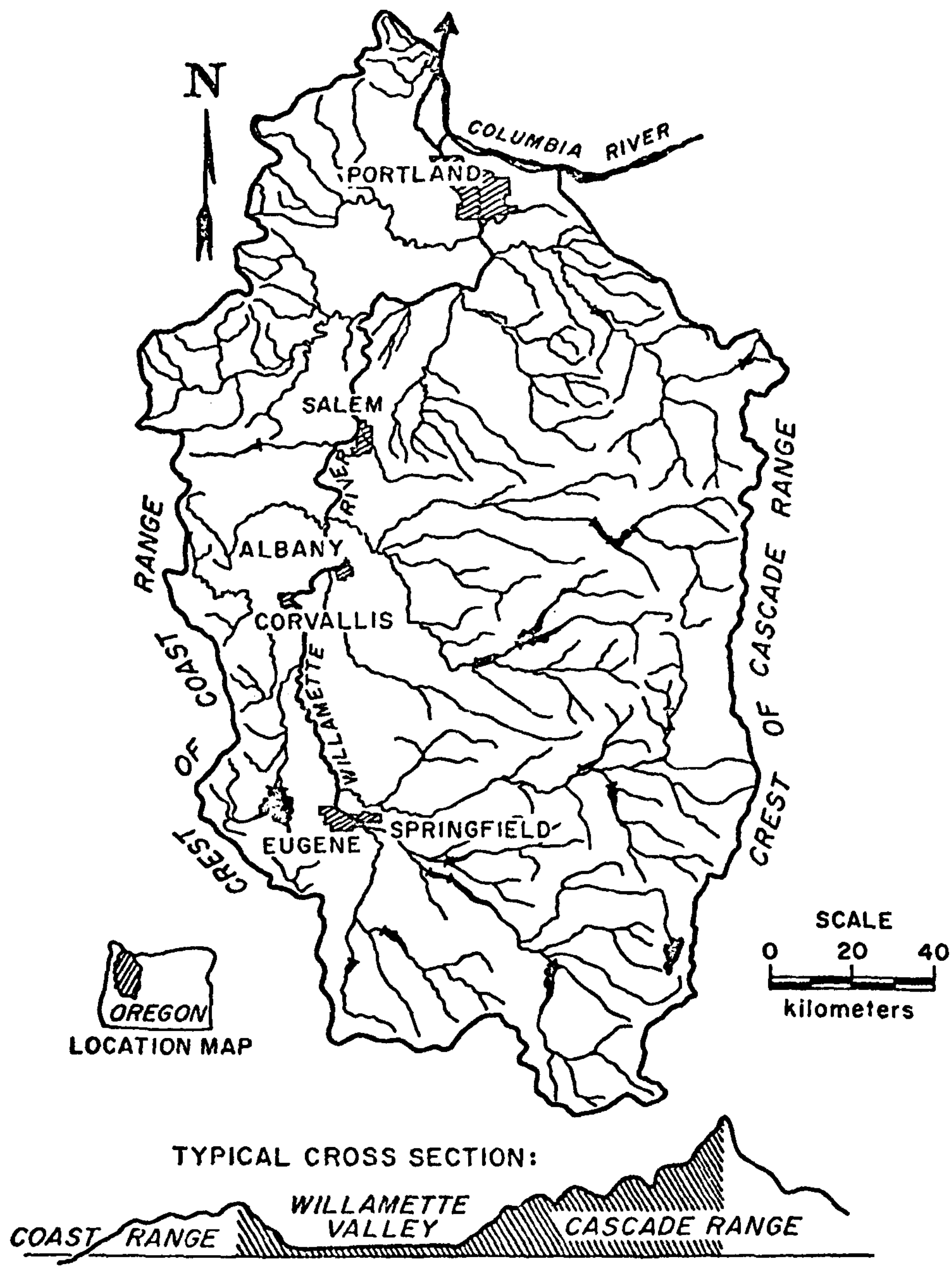

Figure 1. Willamette River Basin

have modifying influences. Annual precipitation varies from 0.9 m (35 inches (in)) on the valley floor to well over 3.3 m (130 in) in portions of the mountain ranges, with a basin average of 1.6 m (63 in).

Approximately 70% of the precipitation occurs between November and March. Temperatures on the valley floor range from a monthly mean of about 4°C (40°F) in January to about 20°C (70°F) in July. Daily temperatures seldom drop below -20°C (0°F) or rise above 40°C (100°F).[4]

Typical monthly values of air temperature and precipitation at Salem, together with Willamette River streamflow and water temperature there are shown in Figure 2. Salem is centrally located on the valley floor (see Figure 1), its climatic and runoff features are representative for the valley, and the climatic and hydrologic records are of comparatively long duration.

RIVER HYDROLOGY

Runoff closely follows the annual precipitation pattern of the basin. Streamflows usually peak in December, January or February and normally reach minimum levels in late summer (see Figure 2). A lesser spring runoff peak corresponds to gradual snowmelt from the higher elevations of the Cascade Range. Stream temperatures generally reflect the pattern for air temperature, as modified by snowmelt runoff (Figure 2).

The main stem originates at the confluence of the Coast and Middle Forks 301 km (187 mi) from its mouth and at an elevation of about 130 m (430 ft), msl. Major tributaries are the McKenzie, Santiam, and Clackamas Rivers, all draining the Cascade Range and foothills, and the Yamhill River, draining Coast Range slopes (see Figure 3). Tributaries from the east have higher base flows in summer months than those from the west, due to melting snow and groundwater storage.

The average annual runoff at successive points along the main-stem Willamette River and from principal tributaries is shown in Table 1. U. S. Geological Survey streamgaging stations provide the reference points for data.

The total Willamette Basin runoff, averaging 30 billion m^3/yr (G m^3/yr) (24 million acre-feet per year), places the river as 12th largest in the United States.

NATURAL RESOURCE USE AND DEVELOPMENT

Almost two-thirds of the Willamette Basin is forested. These lands are predominantly in upland areas. The valley floor and adjacent lands are predominantly devoted to agricultural and grazing uses--about one-third of the basin area. Urban zones and local areas of forest are

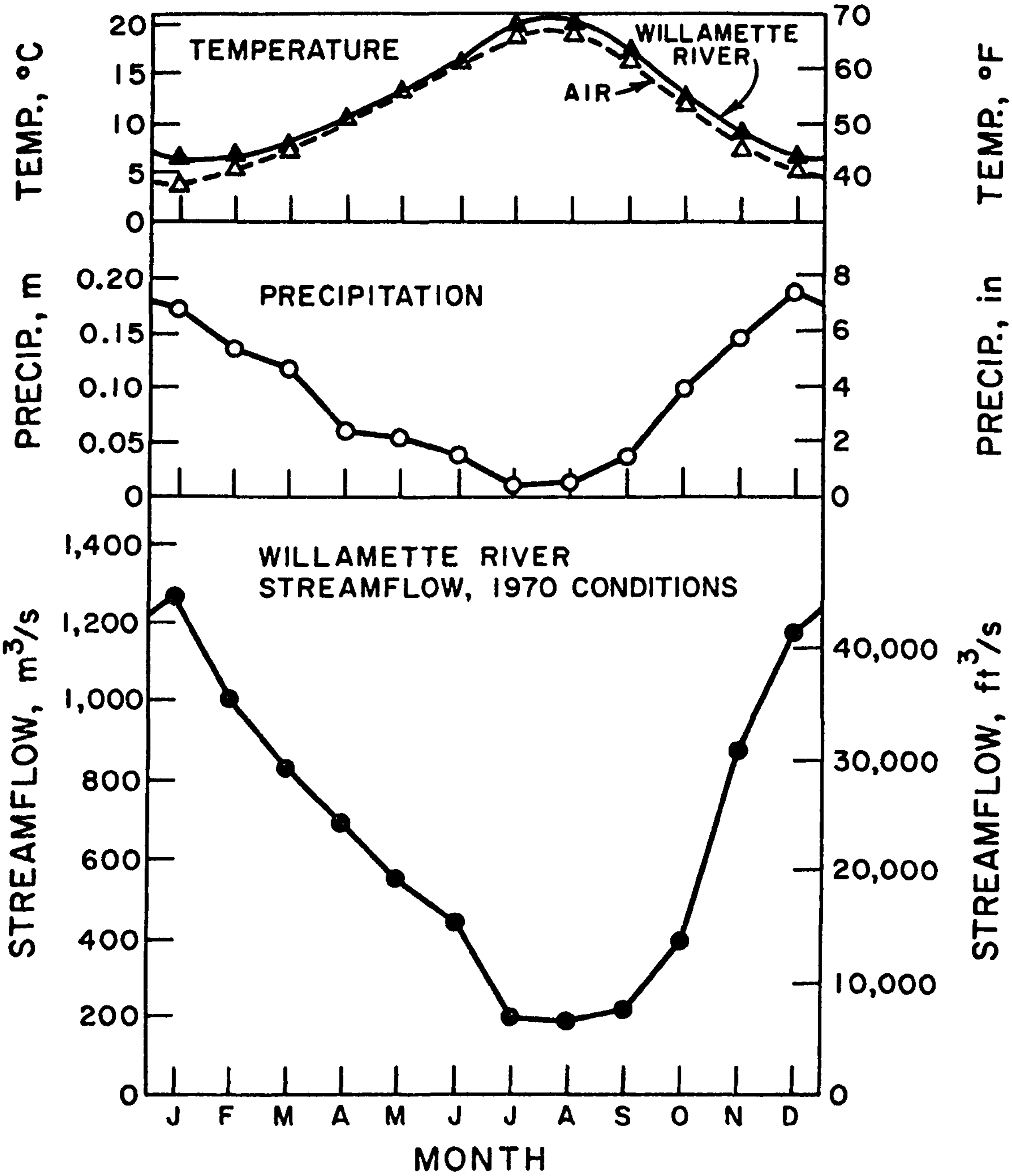

Figure 2. Typical patterns for climatic and hydrologic variables at Salem, Oregon.[2]

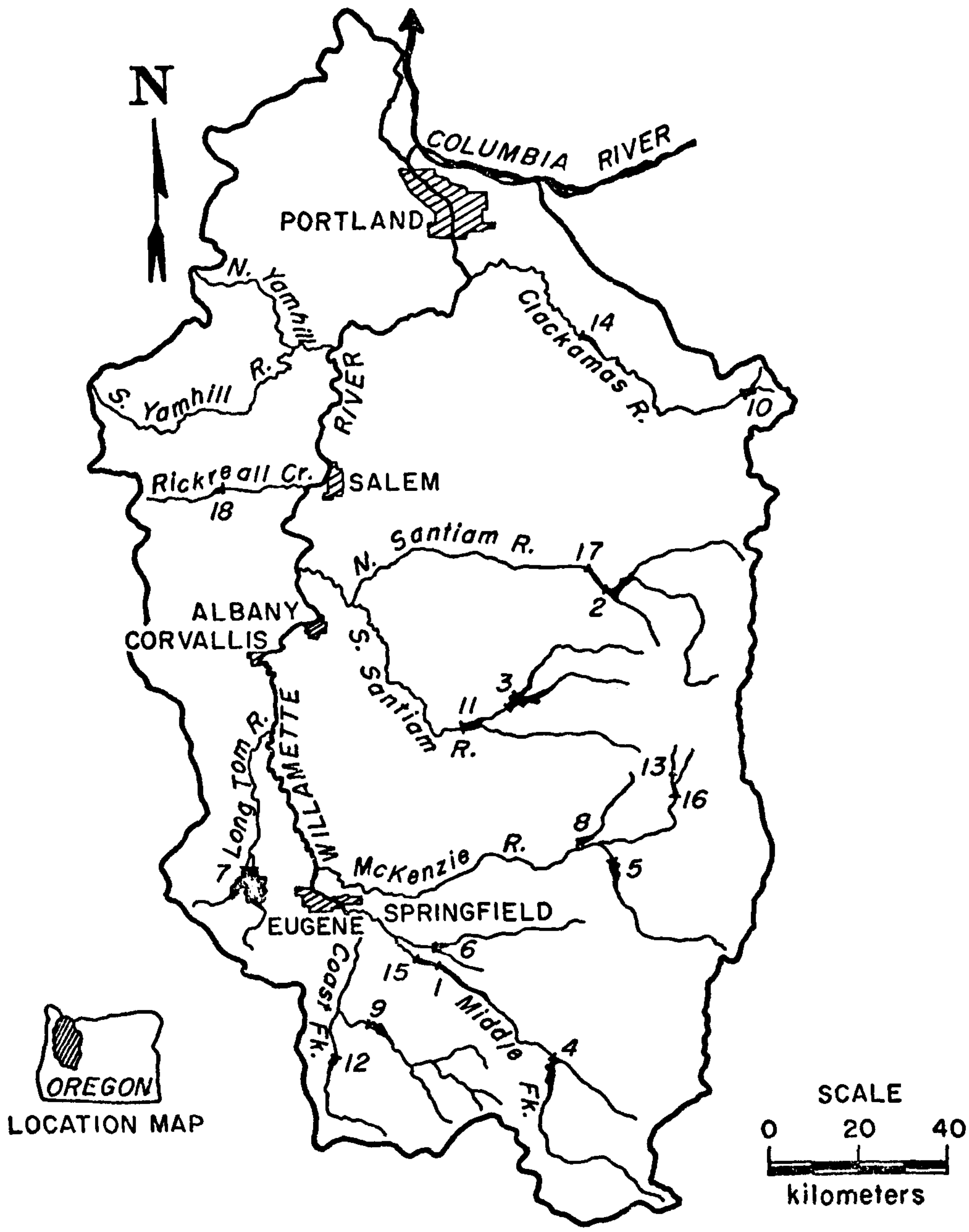

Figure 3. Principal Willamette Basin Reservoirs.

Table 1. AVERAGE ANNUAL RUNOFF FOR THE WILLAMETTE RIVER AND PRINCIPAL TRIBUTARIES[a]

Stream and locations	Drainage area		Average annual runoff			
			Rate		Volume	
	km^2	mi^2	m^3/s	ft^3/s	10^6 m^3/yr	acre-foot/yr
Tributaries						
Coast Fork Will. R. nr. Goshen	1,660	642	48	1,680	1,500	1,220,000
Middle Fork Will. R. at Jasper	3,470	1,340	112	3,970	3,540	2,870,000
McKenzie R. nr. Coburg	3,461	1,337	153	5,400	4,820	3,910,000
Long Tom R. at Monroe	1,010	391	22	780	700	565,000
Marys R. nr. Philomath	412	159	13	460	410	333,000
Calapooia R. at Albany	963	372	26	910	810	659,000
Santiam R. at Jefferson	4,630	1,790	232	8,200	7,330	5,940,000
Luckiamute R. nr. Suves	620	240	25	880	790	637,000
Yamhill R. at Lafayette	1,900	735	64	2,250	2,010	1,630,000
Pudding R. at Aurora	1,240	479	35	1,220	1,090	883,000
Molalla R. nr. Canby	836	323	32	1,130	1,010	818,000
Tualatin R. at West Linn	1,840	710	42	1,490	1,330	1,080,000
Clackamas R. nr. Clackamas	2,420	936	105	3,700	3,310	2,680,000
Main Stem						
Willamette R. at Springfield	5,260	2,030	164	5,780	5,160	4,180,000
Willamette R. at Harrisburg	8,850	3,420	328	11,600	10,400	8,400,000
Willamette R. at Albany	12,500	4,840	408	14,400	12,800	10,400,000
Willamette R. at Salem	18,800	7,280	665	23,500	21,000	17,000,000
Willamette R. at Wilsonville	21,700	8,400	739	26,100	23,300	18,900,000
Willamette R. at Portland	28,700	11,100	934	33,000	29,500	23,900,000

Data are for the period 1928-1963 from reference 2. For tributaries, gaging stations nearest the Willamette River are used. Some reported values are approximate.

interspersed with farming on the valley floor and foothills. Almost half of the basin land area is in public ownership (federal, state, county, municipal).

The economic development of the Willamette Basin is oriented to its natural resources. The basin is a major center for agriculture, timber production, food processing industries, including canneries, and forest products industries, including pulp and paper mills. Business, commerce, government, and learning are significant to the basin economy. Recreational activities are a major facet of basin life and are oriented to fish and wildlife, water sports and out-of-doors activities in the forests and mountains.

Extensive forests cover the majority of the Willamette Basin except on the valley floor. Elevation is the principal determinant of vegetation zones. The valley zone below the 300 m (1,000 ft) elevation level has been extensively converted to agricultural and urban uses. However, scattered forest stands of softwoods and hardwoods occur, including Douglas-fir, cottonwood, alder, Oregon ash, bigleaf maple and white oak.[4] The principal forest zone lies between 300 m (1,000 ft) and 1200 m (4,000 ft) elevations, where much of the timber resource is harvested. Extensive pure stands of Douglas-fir predominate over western hemlock, western red cedar and the true firs. The upper slope forest zone, between 900 m (3,000 ft) and 1,800 m (6,000 ft) elevations and marked by precipitation ranging from 2.3 m (90 in) to 3.6 m (140 in) annually, is primarily commercial forest. The predominant stands are true firs and mountain hemlocks.[4] Meadows, lakes, and rock outcrops are frequent in this zone. The subalpine forest zone above 1,500 m (5,000 ft) of elevation has a very short growing season (30 days). Subalpine firs, mountain hemlock, white-bark pine, and ground juniper are the principal tree species. Tree stands are scattered and mixed with meadows, barren areas and lakes.

Timber-based industries in the Willamette Basin are oriented to the unique character of Douglas-fir stands found in western Oregon and western Washington.[4] Climatic influences have provided an environment which allows a Douglas-fir vegetative system to provide large growth of relatively uniform size and age in particular stands. To sustain this timber resource, a harvesting pattern of patchcutting and clearcutting has been adopted which is highly efficient for commercial extraction.

The temperate, climate, abundant water, and fertile soil with broad capabilities have made agriculture the second most important use of land resources in the Willamette Basin after timber harvesting. On the valley floor, timber stands were removed by early habitants to provide needed space for farming. About 11,000 km^2 (4,400 mi^2) are suitable for cultivation, with 8,800 km^2 (3,400 mi^2) presently used and the remainder forested or in urban use.[4] Soil capabilities to produce crops over long periods vary. About half of the suitable land exhibits excessive wetness due to high water tables, poor internal drainage characteristics of the soil, inadequate drainage outlets, or overflow conditions. This has required crop adaptation and limits productive yields.

Principal crops include grass seed crops, the growth of which is well adapted to land wetness problems. A substantial livestock industry is supported by improved hay and pasture lands. Grain crops, chiefly wheat and barley are grown. The grain and grass crops support the livestock industry during winter months. Fruit and vegetable crops are quite important, among these snap beans, sweet corn and filberts supply a significant fraction of the nation's needs.

Mineral production in the Willamette Basin is not extensive, about $20 million annually.[4] Most of the production focuses on sand, gravel, stone and cement for the construction industry. A great deal of the sand-and-gravel needs have been met from streambeds and adjacent former channels of the valley streams. Production of metallic minerals has been mainly limited to mercury, gold, silver, copper, lead, and zinc. The total value of all such production is relatively small ($3 million since 1900).

Fish and wildlife resources in the Willamette Basin take on a significance far beyond economic importance. This has been attributed to "the pioneer heritage, which orients the Willamette resident to his natural environment" and "has remained as a part of the regional character" with fish and wildlife resources "one of the threads of the total environment that makes the Willamette Basin a desirable place to live".[4]

Resident fish abound in the streams, lakes and reservoirs of the basin. The Willamette main-stem is a migration route for a growing anadromous fish population. Wildlife species are numerous in the basin, both in lowland and upland zones. The Pacific Flyway, a major route for migratory birds, depends upon the Willamette Basin both for migrating and for wintering populations. Lowland streams, lakes, reservoirs, and wetlands are essential for resting and feeding areas.[4]

STORAGE RESERVOIRS

Thirty nine reservoirs in the Willamette Basin have usable storage capacities of 370,000 m^3 (300 acre-feet) or more. The larger reservoirs tend to be federal and the smaller ones privately or municipally owned.

The present federal development of Willamette Basin water resources includes 13 Corps of Engineers (C of E) dams and reservoirs. Ten of these function as storage projects and three serve as reregulating systems to dampen out the streamflow fluctuations caused by hydroelectric power production at dams immediately upstream. The 10 storage reservoirs are (from north to south in the basin): Detroit, Green Peter, Blue River, Cougar, Fern Ridge, Fall Creek, Lookout Point, Hills Creek, Dorena, and Cottage Grove. The 3 reregulating reservoirs--Big Cliff, Foster, and Dexter--are just downstream of Detroit, Green Peter, and Lookout Point, respectively.

The locations of these reservoirs and several private and municipal reservoirs for industrial and power storage in the Willamette Basin are shown in Figure 3. The reservoirs are numbered by order of size (largest = 1) and are described in Table 2. Most are situated in foothill portions of the Cascade Range. Fern Ridge Reservoir is the only "valley floor" project. All reservoirs have similar hydrologic and climatic settings. The watersheds have differing soils and geologic formations.

The hydrologic characteristics of the basin allow most of the flood control storage allocation at reservoirs to be used, outside of the winter flood season, for conservation storage and use. Storing normally occurs between February and May. Storage releases for navigation are designed to provide adequate water for the deep-draft navigation channel from the mouth of the Willamette upstream through Portland, for the shallow-draft navigation lock at Willamette Falls (first built in 1873), and for a shallow-draft channel from the falls upstream to the Albany-Corvallis area. Storage releases for irrigation occur throughout the growing season. Separate storage allocations for exclusive power use are included at several reservoirs. The basin power requirements exceed in-basin generating capacity and hydroelectric generation is required year-around. In late autumn of dry years, additional drafting of some federal reservoirs may be required to supplement hydroelectric generation on the Columbia River. While recreation is not an authorized purpose for most storage projects in the Willamette Basin, it is in fact a significant summer activity and reservoirs are operated to accommodate recreational interests as much as possible. Municipal and industrial storage reservoirs are commonly smaller than 1,000,000 m^3 (1,000 acre-ft) and divert water into pipeline transmission systems for delivery to the user areas.

DEMOGRAPHIC FEATURES

Principal urban centers are Metropolitan Portland, Salem, Corvallis-Albany, and Eugene-Springfield. These and smaller towns and communities are surrounded by agricultural and forested lands so as to maintain vestiges of rural setting. Transportation corridors for highways and railroads provide essential links and weave the communities together. Three-fourths of the basin residents live in urban areas; most live within 20 km of the Willamette River.[4]

Table 2. STORAGE RESERVOIRS IN THE WILLAMETTE BASIN WITH 1 MILLION CUBIC METERS OR MORE OF USABLE STORAGE[a]

Rank	Reservoir name	Stream	Operator[b]	Year placed in operation	Usable storage 10^6 m^3	Usable storage Acre ft	Authorized purposes[c]
1	Lookout Point	Mid Fork Willamette R.	C of E	1954	431	349,400	FC, N, I, P
2	Detroit	N. Santiam R.	C of E	1953	420	340,000	FC, N, I, P
3	Green Peter	Mid Santiam R.	C of E	1966	411	333,000	FC, N, I, P
4	Hills Creek	Mid Fork Willamette R.	C of E	1961	307	249,000	FC, N, I, P
5	Cougar	S. Fork McKenzie R.	C of E	1963	204	165,100	FC, N, I, P
6	Fall Creek	Fall Cr.	C of E	1965	142	115,000	FC, N, I
7	Fern Ridge	Long Tom R.	C of E	1941	136	110,000	FC, N, I
8	Blue River	Blue R.	C of E	1968	105	85,000	FC, N, I
9	Dorena	Row R.	C of E	1949	87	70,500	FC, N, I
10	Timothy Lake	Oak Grove Fork	PGE	1956	76	61,650	P, R
11	Foster	S. Santiam R.	C of E	1966	41	33,600	FC, P
12	Cottage Grove	Coast Fk Willamette R.	C of E	1942	38	30,600	FC, N, I
13	Smith	Smith R.	EWEB	1963	12	9,900	P
14	North Fork	Clackamas R.	PGE	1958	7	6,000	P, R
15	Dexter	Mid Fork Willamette R.	C of E	1954	6	4,800	P
16	Trail Bridge	McKenzie R.	EWEB	1963	3	2,750	P
17	Big Cliff	N. Santiam R.	C of E	1953	3	2,430	P
18	Dallas	Rickreall Cr.	Dallas	1960	1	1,200	M&I

[a] Data Sources: References 2, 4, and 5.

[b] C of E=Corps of Engineers; PGE=Portland General Electric; EWEB=Eugene Water & Electric Board; Dallas=City of Dallas.

[c] FC=flood control; N=navigation; I=irrigation; P=power; R=recreation; M&I=municipal & industrial. All existing Federal reservoirs are used for recreation, even though not so authorized.

The 1970 population of the Willamette Basin is estimated to be 1.4 million.[6] Its distribution within the basin among population centers is shown in Figure 4 and in Table 3. The overall population density in the central and southern part of the basin is about 25 persons per square kilometer, with maximums of about 1,200 persons per square kilometer in the largest urban centers. The overall population density in the northern quarter of the basin is about 120 persons per square kilometer (adapted from reference 4).

WATER SUPPLY DEVELOPMENT

Municipal water in the basin was provided by 78 developments in 1965. About half of these systems, serving 10% of the basin population, were based on ground water sources.[4] About 80% of the municipally-served population obtained their water from the Portland, Eugene, Salem and Corvallis surface water systems. Of these four areas, only Corvallis relies heavily on Willamette River water for the large summer demands; the others obtaining all or most of their supplies from watersheds or large tributaries of the Willamette (Bull Run Watershed, McKenzie River, Santiam River, for Portland, Eugene, and Salem, respectively). Corvallis obtains part of its supply from a municipal watershed also.

Rural domestic water supplies are primarily obtained from ground water sources.

Industrial water demands are met both from municipal systems and from independent sources. Food processing and pulp-and-paper manufacturing represent the most significant industrial water demands in the valley; the former industry is mainly supplied by municipal systems while the latter industry is almost entirely self-supplied.[4] Independent industrial systems rely both on surface water and ground water for their supply.

WASTEWATER TREATMENT FACILITIES

As of 1974 there were 130 municipal and 72 industrial wastewater dischargers operating in the Willamette Basin. While many of the smaller facilities are located on tributaries, the majority of the wastewater effluent, after treatment, is released to the main-stem Willamette River.

The principal operating municipal and industrial wastewater treatment facilities are listed in Table 4. Their locations are shown in Figure 5.

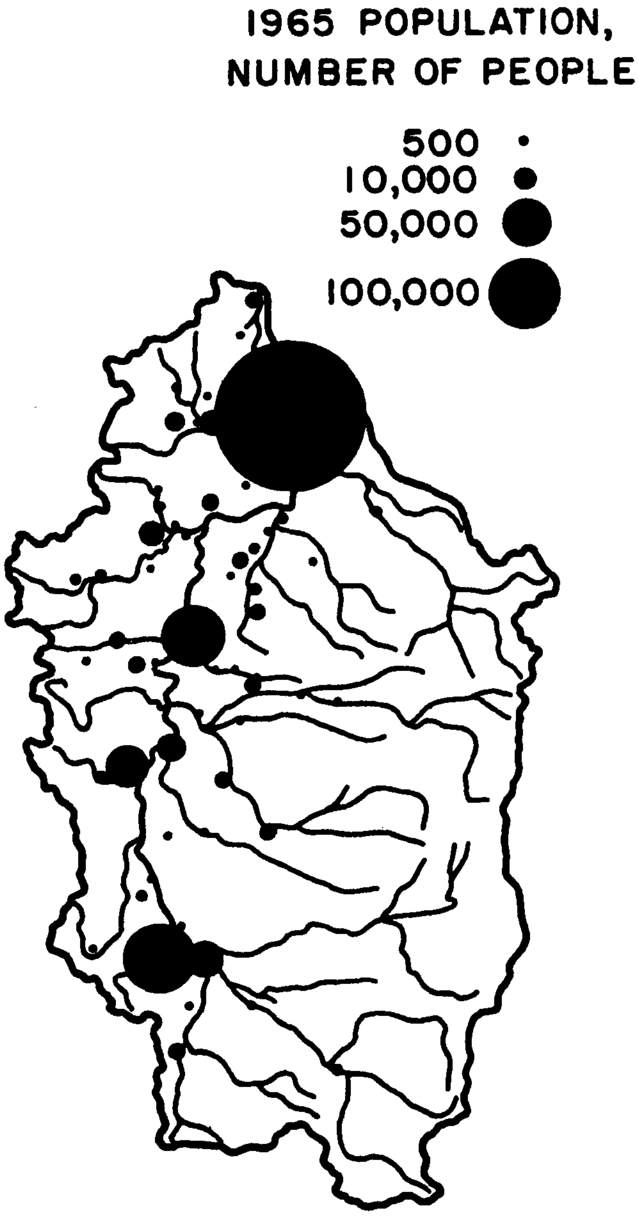

Figure 4. Population centers in the Willamette Basin.

Table 3. POPULATION CENTERS IN THE WILLAMETTE BASIN[a]

Population center	1970 population
Portland	379,967
Eugene	79,028
Salem	68,480
Corvallis	35,056
Springfield	26,874
Beaverton	18,577
Albany	18,181
Milwaukie	16,444
Hillsboro	15,372
Lake Oswego	14,615
Estimated basin population	1,400,000

[a] Source: reference 6.

Table 4. PRINCIPAL WILLAMETTE BASIN MUNICIPAL AND INDUSTRIAL WASTEWATER TREATMENT FACILITIES IN 1974.

Municipal facilities	Industrial facilities
1. Portland-Columbia Boulevard	A. Wah Chang, Albany
2. St. Helens	B. Rhodia, Portland
3. Salem	C. Pennwalt, Portland
4. Eugene	D. Evans Products, Corvallis
5. Albany	E. Boise Cascade, Salem
6. Corvallis	F. Publishers Paper, Oregon City
7. Springfield	G. Publishers Paper, Newberg
8. Portland - Tryon Creek	H. Crown Zellerbach, Lebanon
9. Fanno Creek	I. Weyerhauser, Springfield
10. Oak lodge	J. Western Kraft, Albany
11. Hillsboro - West	K. Crown Zellerbach, West Linn
12. Oregon City	L. American Can, Halsey
13. Milwaukie	M. Kaiser Gypsum, St. Helens
14. Beaverton	N. Stimson Timber, Forest Grove
15. Gresham	O. Boise Cascade, St. Helens
16. Metzger	P. Oregon Metallurgical, Albany
17. Forest Grove	Q. Union Carbide, Portland
18. McMinnville	R. General Foods, Woodburn
19. Sunset Valley	S. Tektronix, Beaverton
20. Lebanon	T. Pacific Carbide & Alloys, Portland

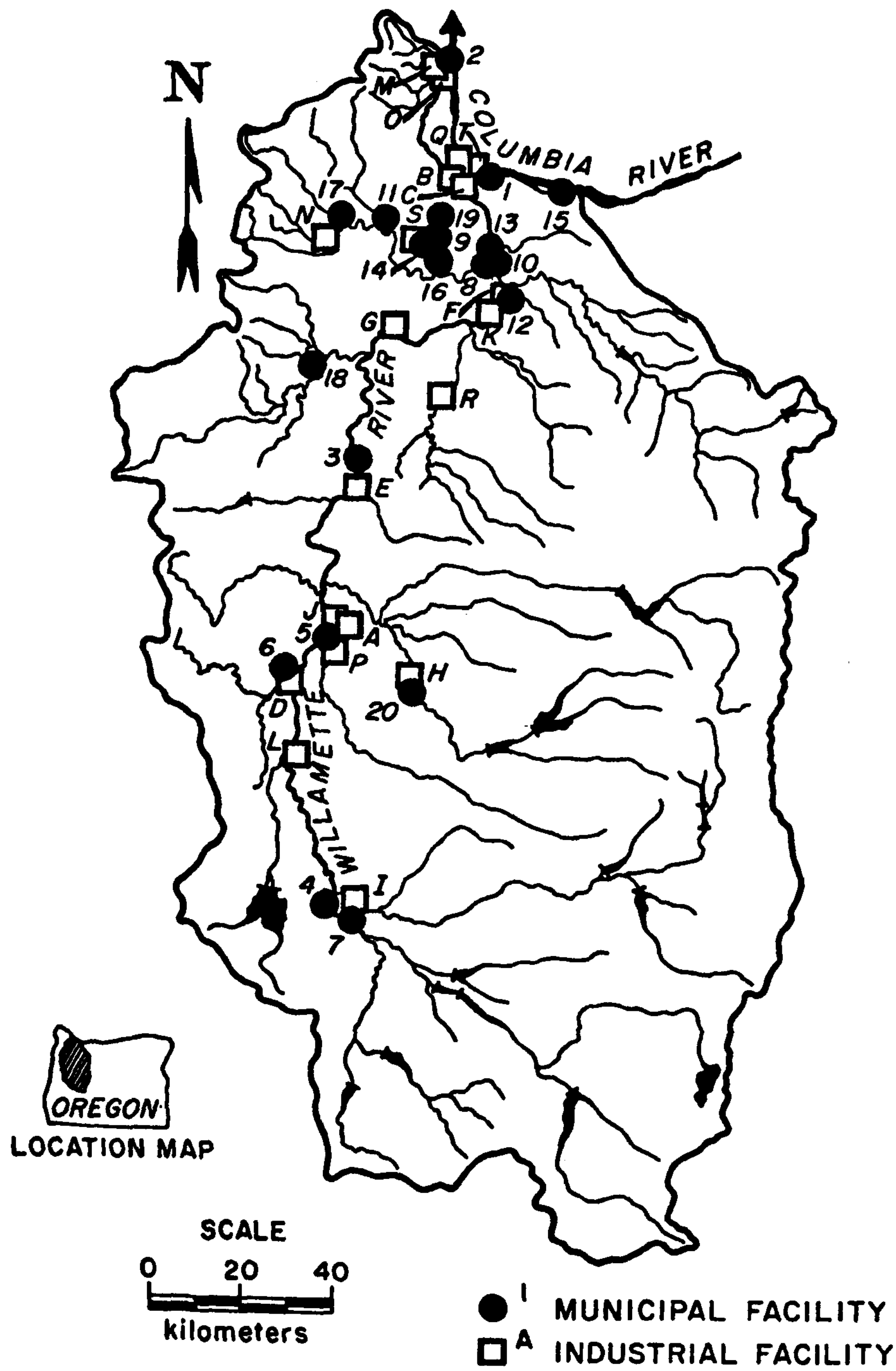

Figure 5. Principal Willamette Basin municipal and industrial wastewater treatment facilities in 1974.

SECTION V

THE STRATEGY USED TO CLEAN UP THE WILLAMETTE

DEFINITION OF TERMS

The term "strategy" finds relatively little use in legislation establishing and regulating the functions of agencies which serve the public. Its use is equally scarce in agency statements of mission, program, and goals. However, the word is becoming more common in present-day environmental planning. To describe the "clean-up" strategy used for the Willamette River, several terms must first be defined.

Strategies for water quality planning and decision-making are here considered to be the concepts and procedures followed in the comprehensive employment of available resources to accomplish set goals. Tactics are here considered to be the processes, methods, and maneuvers followed for the immediate or local employment of resources to accomplish elements of the set goals. Tactical plans and actions are subordinate to strategic plans and strategic plans are limited by tactical capabilities.

A mission is here considered to be the business with which an agency is charged or the orientation that provides focus for the agency's efforts. Thus an agency may have a developmental, regulatory, or protective mission. A goal is construed to be a statement of purpose, aim, or aspiration describing the end that the agency strives to attain; the end toward which agency effort is directed. A goal is describable at various levels of generality; its attainment is therefore often difficult to judge. An objective is a translation of a goal into a more specific, operational statement with a definite target, the attainment of which is much more readily judged. In translating a broader goal into more specific terms it may be necessary to describe several objectives so that essential, unexpressed elements of the goal are retained (i.e., several objectives may be consistent with a single goal). Objectives are associated with goals. Guidelines are here considered to be an agency's stated suggestions and recommendations for ways in which objectives can be met. Guidelines are normally expected to be followed unless deviations from the guidelines are justifiable. Principles are the ethics and rules that dictate how an agency will act and conduct itself on particular matters. Policies are guiding principles on which an agency is assumed to base a course of action that will lead toward achieving a goal or objective. Therefore, principles, particularly guiding principles (policies) must be consistent with established goals and objectives.

Tactics, then, are the actions taken by an agency in order to meet its functional objectives. Strategies, on the other hand, are more closely related to the translation of agency mission into accomplishable goals. Strategies derive from the formulation of approaches by which the goals (and hence the mission) of the agency can be met. Policies and principles express the conduct that the agency itself expects to follow in carrying out its strategies and tactics to fulfill goals and objectives. Guidelines express the non-compulsory conduct that the agency expects others to follow in order to assist the agency in carrying out its strategies and tactics to fulfill goals and objectives.

THE SEARCH FOR AN APPROACH TO POLLUTION CONTROL

The history of efforts to improve water quality in the Willamette River is given an excellent, detailed review by Gleeson[7] in "The Return of a River". Much of this work was given broad national exposure in "The Fourth Annual Report of the Council on Environmental Quality".[8] A few salient points are summarized in the following paragraphs.

Awareness of the deplorable water quality in the Willamette River and an outcry to do something about the problem came early in the 1900's, principally from aroused citizens, the Oregon State Board of Health (created in 1903), and the U. S. Public Health Service. Chemical analyses of Willamette River water were first made in 1910. Laws related to pollution were adopted by the State as early as 1919 but were ineffectual in dealing with the pollution problems of the Willamette River. The 1920's and 1930's provided the first extensive field surveys and tests to determine the sources and severity of river pollution, with numerous reports presented. The number of advocates of pollution abatement grew during this period. The period ended with the passage of an initiative measure by the people in 1938, creating the Oregon State Sanitary Authority (OSSA). This Authority initiated its pollution abatement efforts in 1939. However, the program was delayed by World War II. Further detailed studies of river pollution were conducted by OSSA from 1944 onward and documented the worsening condition of the river through the 1950's. The absolute pollution load of the Willamette River probably was greatest by the late 1950's and early 1960's, according to indirect measures such as dissolved oxygen level (DO) and biological oxygen demand (BOD) of the river water.

Until 1935, there was nothing approaching a pollution control strategy for the Willamette River. In that year, a Stream Purification Committee under the Oregon State Planning Board was created to study, among other topics, the Oregon Law dealing with stream pollution.[7] It was found that existing laws were unrelated, uncoordinated, lacking in direct responsibility for enforcement, overlapping and duplicating, too drastic in their penal sections, probably unconstitutional in some sections, impractical of enforcement, lacking in proper delegation of administrative powers, lacking in direct control over municipalities, and impossible as regards progressive, amelioratory regulation. From a subsequent review of statutes known to be effective elsewhere, 17 "principles" were set out that should be embodied in effective anti-pollution legislation.

Thus, by 1938 a framework for an approach to pollution control existed on paper.

Meanwhile, the press of events led to the initiative measure creating the OSSA. With passage, an agency was born that was to lead the way in abating the pollution of the Willamette River.

A STATE AGENCY FOR WATER QUALITY CONTROL

Passage of the "Water Purification and Prevention of Pollution Bill" in the 1938 election created the State Sanitary Authority as a division within the Oregon State Board of Health. OSSA consisted of six members: the State Health Officer, the State Engineer, the Chairman of the Fish Commission, and three members appointed by the Governor, one from each of Oregon's three Congressional districts.

OSSA was organized in February 1939. However, funding was insufficient at first to allow the employment of adequate staff personnel to carry out fully the program specified by the 1938 act. With time the engineering staff grew, although initially considerable reliance had to be placed on voluntary cooperation with others in order to develop the Authority's program. OSSA's administration functions were enlarged in 1959 to include the State's air quality control program.

Over the years, OSSA evolved the standards of quality for the public waters of the State from the base established in 1938. During this period, numerous changes in the laws were made to update and strengthen the State program of water quality control.

The Oregon Legislature, on July 1, 1969, replaced the then-existing State Sanitary Authority with the newly created Department of Environmental Quality (DEQ), separate from the OSBH. The DEQ consists of an Environmental Quality Commission, a Director, and professional and support staff. The five lay Commission members are appointed by the Governor, subject to confirmation by the State Senate. The Commission "establishes policy for guidance of the director and staff, reviews and confirms or modified staff actions, adopts rules and regulations, issues orders and authorizes and directs legal enforcement actions".[9]

A STATE POLICY ON WATER POLLUTION

Oregon's first comprehensive pollution control policy was expressed by the water quality control laws passed in 1938. These laws were substantially modified by the State Legislature in 1961 and further changed at each succeeding legislative session. In 1967 these laws were completely rewritten and greatly strengthened. In addition, the standards and programs of the OSSA and DEQ have likewise been dynamic (rather than static) in the sense of changing to meet the altered conditions encountered over the years.

The present policy of the State,[10] as embodied in Oregon Revised Statutes (ORS) Chapter 449 Section 077, first recognizes that "the pollution of the waters of this state constitutes a menace to public health and welfare, creates public nuisances, is harmful to wildlife, fish and aquatic life and impairs domestic, agricultural, industrial, recreational and other legitimate beneficial uses of water" and that "the problem of water pollution in this state is closely related to the problem of water pollution in adjoining states." It is then "declared to be the public policy of the state to:

- conserve the waters of the state;
- protect, maintain, and improve the quality thereof for public water supplies, for the propagation of wildlife, fish and aquatic life and for domestic, agricultural, industrial, municipal, recreational and other legitimate beneficial uses;
- to provide that no waste be discharged into any waters of this state without first receiving the necessary treatment or other corrective action to protect the legitimate beneficial uses of such waters;
- to provide for the prevention, abatement, and control of new or existing water pollution;
- to cooperate with other agencies of the state, agencies of other states and the Federal Government in carrying out those objectives."

The original state policy, established in ORS 449.077 in 1938 and only slightly revised 23 years later by action of the state legislature in 1961, was a considerably more general statement. It reflected the concern of the state and the need for standards of purity but did not mention the specific strategy which later evolved. This strategy is referred to in the present policy with the words "first receiving the necessary treatment or corrective action". The original policy, with slight revision in 1961,[11] was to:

"(a) Maintain reasonable standards of purity of the water of all rivers, streams, lakes, watersheds and the coastal areas of the state consistent with the protection and conservation of the public health, recreational enjoyment of the people, the economic and industrial development of the state, and for the protection of human life and property and conservation of plant, aquatic, and animal life.

(b) Foster and encourage the cooperation of the people, industries, incorporated cities and towns and counties in preventing and controlling the pollution of those waters."

Most significantly, the original 1938 act provided a flexible framework to implement the expressed state policy, a framework which could be modified and updated over time to assure reasonable water purity as conditions in the Willamette Basin changed over the years. This framework to carry out the goals and objectives was embodied in ORS 449.086, which gave the Commission of the OSSA the authority to establish standards of water quality and purity. Hearing procedures were established and responsibility for compliance with standards was clearly stated.

The standards of water quality which the OSSA (and later the DEQ) was to establish, maintain and upgrade thus became the mechanism for the state to achieve pollution abatement. The standards provided a framework against which to judge if pollution abatement was in fact being achieved. They could therefore be used as the means of supporting a pollution control strategy and giving guidance as to the necessary tactics to undertake in order to assure the success of that strategy.

A POLLUTION CONTROL STRATEGY: STANDARDS OF WATER QUALITY AND AT-SOURCE WASTE TREATMENT

The translation of state policy and OSSA mission into accomplishable goals required some type of strategy or guiding course of action. The nature of the strategy had been expressed in the original 1938 act: "...maintain reasonable standards of purity of the water..."

In effect, the water pollution control strategy used by the State of Oregon has been to establish and maintain effective standards of quality and purity for the waters of the state and to require appropriate measures of at-source wastewater treatment so that these standards will be met.

The statutory authority of ORS 449.086 permitted OSSA (later DEQ) to issue Administrative Orders concerning these water quality standards. In 1947 OSSA adopted regulation I entitled "Standards of Purity for Waters of the State of Oregon and General Requirements for the Disposal Therein of Sewage and Industrial Waste". These standards were published under Chapter 340, Oregon Administrative Rules (OAR). In addition to the "Standards" in OAR, Subdivisions of Chapter 340 now include consideration of sewage and waste treatment plant operation, disposal of industrial wastes, construction and use of waste disposal wells, regulations pertaining to waste discharge permits, and state financial assistance to public agencies for construction of pollution control facilities.[12]

The essence of the current water quality standards is to: (a) require the highest and best practicable treatment and control of wastewater; (b) place restrictions on the discharge of sewage and industrial wastes and human activities that affect water quality; (c) maintain the standards of water quality; (d) implement treatment requirements; (e) specify general water quality standards that apply to all State waters; and (f) delineate special water quality standards designed to protect beneficial water uses in specifically designated waters.

The general water quality standards prohibit the discharge of wastes or the conduct of activities which either alone or in combination with other wastes or activities cause effects which deviate from the established criteria. The criteria applicable to surface waters address: dissolved oxygen concentrations; hydrogen ion concentrations; liberation of dissolved gases; fungi and other growths; creation of tastes, odors, toxic or other undesirable conditions; formation of bottom deposits, sludge deposits or other organic or inorganic deposits; objectionable discolorations, turbidity, scum, oily slicks or floating solids; bacterial pollution; temperature increases; offensive aesthetic conditions; and radioisotope concentrations.

Special water quality standards that go beyond the general standards have been applied to several rivers, including the Willamette and some of its tributaries. These set more stringent criteria for measuring dissolved oxygen, Coliform organisms, turbidity, temperature, and dissolved chemical substances.

The water pollution control strategy required that compliance be made with the established standards by appropriate means of controlling waste discharges and related activities at their sources. However, in order to determine what those means might be (i.e., to evolve the tactics that would allow accomplishment of the strategy) it was necessary to measure the condition of the river in comparison with the criteria for desirable water quality. Therefore, the irregular river sampling, carried out in the early 1900's to determine the poor condition of the river, had to be changed in emphasis. Problem areas had to be better pinpointed along the river and the relative influences of various types of waste discharges upon the river condition better understood. This called for routine river sampling. More recently, continuous monitoring was instituted by means of which compliance with the water quality standards could be checked, verification could be made that waste discharges complied with permits regulating those discharges, and violations of the standards could be recognized for enforcement purposes.

Determination of the appropriate measures to accomplish at-source wastewater treatment required an evolutionary period of almost three decades. In effect, this part of the pollution control strategy consisted of a sequence of try-and-see tactics, each going one step further in at-source wastewater treatment, followed by a period of observation of the river condition in order to discover the degree of water quality improvement brought about by the particular tactic. Unfortunately, as far as such an approach was concerned, the Basin population, industrial base and wastewater characteristics did not remain static during the intervening years. Thus, tactics overlapped whenever it became clear that those currently being tried were not closing the "pollution gap" rapidly enough. Consequently, the effectiveness of individual tactics was not always directly measurable.

POLLUTION CONTROL TACTICS: ACTION UNDER THE STRATEGY

The early river sampling surveys had shown water pollution to be severe downstream from the effluent discharges of municipalities along the mainstem Willamette River. Consequently, as the newly formed OSSA began to gather better data on the river's waste loads and water quality there was already enough factual information to form the basis for some immediate actions. Thus, in 1939 the first of over a half-dozen distinct, overlapping tactics was initiated as the OSSA began the "game of catch-up" on Willamette River water quality which was to last for over three decades, until the early 1970's.

Tactic 1: Primary Wastewater Treatment for Mainstem Municipalities

One of OSSA's first actions when its program was started in 1939 was to notify all municipalities and industries of their responsibility under the new law to install adequate sewage and waste treatment facilities.[11] OSSA adopted a regulation which included provision for a minimum dissolved oxygen content of 5 parts per million (PPM) or milligrams/liter (mg/l). It was thought that the early standards of water quality adopted by OSSA could be met if most of the municipalities on the main stem of the Willamette River undertook primary treatment of wastes, followed by effluent chlorination. Primary treatment was considered to mean the removal of not less than 35% of the average 5-day BOD and at least 55% of the suspended solids. Therefore, Tactic 1 was to require mainstem Willamette municipalities to install primary treatment of wastes.

In response to instructions from OSSA, municipalities began in the 1940's to plan for the installation of the necessary treatment facilities. The first compliance with this tactic was in 1949, when primary treatment plants were completed at two cities. By 1957 all municipalities on the main stem of the Willamette River except Portland had complied with the original directive. Portland, with its numerous outfalls for raw wastes, had intercepted most of these outfalls and was providing primary treatment of the intercepted wastes before discharging them directly to the Columbia River, where much greater dilution flows were available.

Evaluation of the effectiveness of this tactic was facilitated when OSSA began routine river sampling in 1950. Periodic surveys were also conducted on a more comprehensive scale. The first comprehensive OSSA survey, in the summer and fall of 1957, showed that the degree of treatment in effect at that time was still insufficient to meet the water quality standards.[11]

Tactic 2: Sulfite Waste Liquor Control by Pulp-and-Paper Mills on the Willamette.

The second tactic was directed toward control of industrial wastewater discharges from the sizeable pulp-and-paper firms located on the Willamette River. Prior to a public hearing in early 1950, little had been accomplished toward abating pollution from such sources. Sulfite waste liquors entering the river from pulp-and-paper mills between Salem and Portland were reportedly responsible for about 84% of the total pollution load in the river (based on oxygen demand), exclusive of pollutant loads from tributary streams and the city of Portland.[11]

An order was issued by OSSA in May 1950 that the pulp-and-paper mills, by May 1952, cease discharging concentrated sulfite waste liquor into the main Willamette River during July, August, September, and October of each year and at all other times when the Willamette River flow at Salem was less than 200m^3/s (7,000 cfs). An analogous directive applied to a mill responsible for about 91% of the oxygen demand on the South Santiam River.

Therefore, Tactic 2 was to require that particular pulp-and-paper industry wastes that exerted a large oxygen demand be held from the river during those low-flow periods when such a demand could be most deleterious to the river.

In response to this order, the several mills developed plans for special treatment and disposal facilities. The facilities developed included evaporative concentration followed by either burning or spray drying for by-product recovery, impoundment for later release during periods of higher streamflow, and barging of concentrated spent sulfite liquor to the Columbia River for disposal.

The 1957 comprehensive survey of river pollution sources showed that wastes from the sulfite pulp-and-paper mills still represented about 64% of the total oxygen demand of all pollution loads discharged to the Willamette and its major tributaries.

Tactic 3: Selective Secondary Treatment and Accelerated Progress in Primary Treatment

Considerable progress in primary treatment had been made by 1957. In spite of this, certain stretches of the Willamette River fell far short of desirable water quality. The continued increase of population and expansion of industry, together with urban growth that outstripped efforts to provide adequate sewerage facilities, all contributed to the continuation of pollution problems.

The unsatisfactory condition of the Willamette River shown by the 1957 survey led to decisions by OSSA in 1958 which are here represented as tactic 3. These included instructions to the cities of Eugene, Salem and Newberg (each with high industrial waste loadings) to install secondary sewage treatment facilities, the city of Portland to accelerate its program for intercepting and treating raw wastes, and the pulp-and-paper mills to further reduce their pollution loads.

Eugene was able to comply by 1961. Progress for the other cities was slower. Public hearings had to be held, the outcome of which was to set deadlines for compliance with the directive in some instances and a court complaint against Portland which was only dropped after an election vote in 1960 to finance new construction.[11]

Tactic 4: Secondary Treatment for All Lower-Willamette Municipalities

Close on the heels of tactic 3, tactic 4 was implemented in 1960 following a public hearing. The new directive was that all municipalities along the lower Willamette River from Salem downstream were to construct secondary treatment facilities.

The momentum favoring construction of wastewater treatment facilities was showing results. By 1965 compliance with this tactic was essentially complete except for the lower river in Portland, where some raw waste outfalls had not yet been intercepted.

Assessment in 1964

The pollutant load imposed upon the Willamette River appears to have reached its peak in the late 1950's and early 1960's, dependent upon which data are used and location along the river. The 1964 OSSA report on water quality and waste treatment needs for the Willamette utilized prediction curves and procedures developed by Velz for the pulp-and-paper industry to calculate waste treatment requirements to meet the established water quality standards. The OSSA concluded from Velz's work that minimum removals of 85% BOD_5 and settleable solids were required so as to prevent oxygen depletion and sludge deposits in the river. Effluent chlorination continued to be essential. Further, it was determined that any significant increases in waste loads would require even greater reductions of oxygen demanding substances and settleable solids if acceptable water quality in the Willamette River was to be achieved and maintained. In spite of all the municipal and industrial wastewater treatment facilities installed by 1963, the water quality of the Willamette River "was still considerably below the standards set by the Sanitary Authority".[11]

Tactic 5: General Secondary Treatment and Year-Around Primary Treatment at Pulp Mills

The assessment of Willamette water quality in 1964 by OSSA resulted in tactic 5. This required: (a) year-around primary sedimentation or equivalent treatment for removal of settleable solids for all industrial wastes from each pulp-and-paper mill; (b) the additional requirement at each sulfite pulp-and-paper bill;during the period of critical river flow from June to October, inclusive, for an overall reduction of 85% in BOD loadings of effluents from the entire mill; (c) a minimum of secondary treatment, or equivalent, from all other sewage or waste effluents to provide not less than 85% BOD removal and to include chlorination for sewage effluents; (d) an even higher degree of sewage and industrial waste treatment in some cases (depending on size and nature of waste load and receiving stream); and (e) a deadline of December 1, 1966, to install the needed treatment facilities.

Although the December 1966 deadline was not met by all of the affected companies, sufficient progress was made so that in 1967 a significant change in Oregon's water quality control laws was made which changed the emphasis from pollution abatement to pollution prevention and water quality enhancement.[9] The signs pointed to successful achievement of the pollution control strategy within the near future. There remained, however, several measures or tactics to implement in order to assure the success of this strategy.

Tactic 6: Secondary Treatment Established as Minimum Level

As a modification of tactic 5, tactic 6 was established in 1967 requiring all wastewater discharged into any of Oregon's public waters to receive a minimum of secondary treatment. Provision was made that levels higher than conventional secondary treatment might be required, in which case the standards would include specific treatment requirements and effluent limits. Year-around secondary treatment for Willamette Basin dischargers was scheduled to be in effect prior to the 1972 low-flow season.[9]

Tactic 7: Specific Waste Discharge Permits

Another significant tactic to promote and protect the pollution control strategy was the introduction in 1968 of the waste discharge permit, required for any wastes discharged into the public waters of the state. The permits contain definite limitations on quantities and strengths of wastes that could be discharged. Characteristically, numerical limits are included on pounds of BOD and suspended solids, pH, bacteria, temperature, color, turbidity, and toxic elements. In cases where treatment or control is inadequate at the time of permit application, a specific, detailed program and timetable to achieve fully adequate treatment is included in the permit.[9]

By 1968, all major and many minor point-source waste discharges had been identified. The permits provided OSSA (and now DEQ) with an effective mechanism to inventory all waste discharges to state waters. These permits also provide an effective means of regulation of the waste load entering these waters over time.

Supporting Tactics

While seven specific actions to achieve the pollution control strategy have been identified and even given a chronological number, many supporting actions and tactics have also been used by OSSA and, since July 1969, by DEQ to achieve water quality control.[9] These include:

- promotion of the idea of water pollution control;
- promotion of the installation of public sewer systems and wastewater treatment and control facilities;
- review and approval of plans and specifications for all wastewater treatment and disposal projects;
- stream monitoring for pollution control;
- comprehensive stream surveys to study pollution problems;
- inspection and efficiency tests of wastewater treatment plants;

- training of wastewater treatment plant operators and staff;
- separation of storm and sanitary sewer waters to reduce treatment plant loads and prevent bypassing of sewage flows at times of high runoff;
- basic data collection on water quality;
- investigation of complaints and holding of public hearings;
- enforcement of the pollution control laws, regulations, and permit conditions;
- processing of applications for Federal and State sewage works construction grants;
- State construction grants program for sewage works;
- certification of industrial waste control facilities for tax credits; and
- a tax relief program.

Results of the Strategy and Tactics

The pollution control strategy of establishing standards of water quality and requiring appropriate measures of at-source wastewater treatment to meet these standards was supported by numerous tactics and related actions. By 1970 it was apparent that the strategy was achieving success, even though the full effects of some then-ongoing tactics were not yet evident. The municipal and industrial waste loads entering the Willamette River had been drastically cut in terms of absolute amounts. While waste concentrations tended to be influenced by the degree of summer augmentation of river flow from reservoir storage, the absolute loading directly demonstrated that river pollution had been controlled and reduced. Municipal waste discharges (including industrial waste components) during the 1970 low river flow season were reduced 89% on an overall basis and industrial waste discharges were reduced 86% overall.[9] Both the municipalities and the industries of the Willamette Basin have been assigned essentially fixed limits of BOD discharges by the DEQ, so that future growth and development must be accompanied by increased treatment efficiency with no increase of the waste load entering the river.

RELATED FEDERAL STRATEGIES AND TACTICS

Passage of PL 80-845, the Federal Water Pollution Control Act, by the U. S. Congress in 1948 drew the Federal government into post-war pollution control planning in the Willamette Basin. The Federal strategy at that time appears to have been one of stimulating cooperative action among Federal, state, local and private groups to formulate comprehensive programs for water pollution control that would conserve a broad range of beneficial uses on interstate waters and their tributaries. One result of this act was a report by the U. S. Public Health

Service, in cooperation with OSSA, on water pollution control in the Willamette Basin. This report, based on data available in 1950, was intended as a reference point for measuring future progress in pollution control and as a basis for developing comprehensive plans and financial assistance programs.[14]

A critical constraint upon the rate of progress in solving the pollution problems in the Willamette River was the limitation of adequate financing for sewerage and sewage treatment facilities. Voter approval was required to finance the majority of such community projects. Financing came from borrowed money obtained through the sale of general obligation bonds, direct property assessments, and sinking funds accumulated by special tax levies or sewer rental charges. Private industry financed its waste control from internally derived funds. Prior to 1956, no Federal assistance programs were available to influence the pace of water pollution control for the Willamette River.

In July 1956 Congress passed Public Law 84-660, the 1956 Federal Water Pollution Control Act, which included a ten-year program of financial assistance to communities for construction of sewage treatment works. This covered only a portion of the total costs, but encouraged and extended the effectiveness of state and local funding. In Oregon, the OSSA had responsibility for reviewing and approving applications for grants and for assigning project priorities based on financial and water pollution control needs. The 1956 act was amended in 1961 and 1965 to increase the appropriations for construction of wastewater treatment facilities and to extend the period of the program.

During the 1960's, other Federal grant programs came into being to finance the construction of sewer systems and sewage treatment facilities. These required cost-sharing by state and local participants. As with the Water Pollution Control Act, these programs significantly aided in spreading the financial burden and stimulating new construction.

The 1956 Federal Water Pollution Control Act and its subsequent amendments provided for comprehensive water pollution control programs, including a review of the water quality control benefits of proposed Federal reservoirs. As had the earlier 1948 act, the 1956 act and amendments served to encourage the ongoing efforts of OSSA to control water pollution in the Willamette River.

On a more sweeping basis, the Federal Water Quality Act of 1965 (PL 89-234), added vitality to pollution control efforts in the Willamette Basin. This Federal legislation required that states adopt water quality standards and enforceable implementation plans to assure waste treatment measures that would control sources of water pollution. The Federal government also took a more active role in the Basin's water quality management, joining forces with the State to develop a wide-ranging pollution control program in 1967.[15] Oregon already had water quality standards and implementation programs to provide waste treatment facilities. The 1965 amendments to previous Federal water pollution control legislation led Oregon to revise and update its general and special water quality standards in 1967. These new standards were among the first approved by the Federal government, thereby becoming also Federal standards subject to Federal enforcement.

In retrospect, Federal activities aimed at pollution control by means of at-site waste treatment have been significant in the Willamette Basin for their support rather than guidance of State policy. The State and its electorate made its commitment to pollution control in 1938 and provided leadership for guiding state policy by creation of the State Sanitary Authority. But the road to success was difficult and the financial burdens heavy. The Federal grants for waste control facilities brought financial support during critical years of population and industrial growth when a slower-paced program would have made it very difficult to make gains against water pollution. Beyond financial support, the Federal concern over State water pollution problems exerted its influence over State water policy in other ways, among these being the stimulus for new water quality standards in 1967 and the beneficial effects of cooperative programs. The U. S. Public Health Service, for example, was an active cooperator with the State in data gathering and other ways early in the century and has remained so over the years, along with newer Federal organizations.

AN OLD STRATEGY UPDATED: WASTE DILUTION BY FLOW AUGMENTATION

The traditional method of waste disposal practiced over centuries by riverbank communities was to release untreated wastes directly to streams, thereby diluting the strengths of such wastes and, hopefully, allowing them to be assimilated by the receiving waters. This approach was used by communities and industries along the Willamette River well into the 1950's, even though adverse pollutional effects had been evident for decades. The waste dilution method was even refined in the lower river to the extent that certain industrial wastes were being barged to the Columbia River for dumping, where the diluting flow available was more than an order of magnitude greater than in the Willamette. Even Portland, after giving primary treatment to sewage flows, was releasing these wastes to the Columbia River rather than applying secondary treatment before releasing effluent to the Willamette River. But the old standby method of waste dilution failed in the face of population and industrial growth in the Willamette Basin.

The same growth of population and the industrial base that aggravated the severe water pollution problems brought with it other needs, such as flood control. Measures taken to alleviate flood control led to construction and operation of Federal storage reservoirs by the U. S. Army Corps of Engineers. These became the means for a new strategy in the battle against water pollution--waste pollution control by means of flow augmentation and the resulting dilution of wastewaters.

Over the years, the OSSA and DEQ, in their biennial and annual reports, have cited the pollution control benefits gained in the Willamette River because of summer streamflow regulation by release of impounded waters from upstream storage reservoirs. For instance, the 1960 report recognized that maintaining a reasonable degree of purity in the Willamette River along with future population and industrial growth make it absolutely essential that flows be augmented considerably in the lower Willamette during the critical summer and fall months. Such augmentation was considered to be a "supplement to and not as a substitute for sewage and waste treatment."[13]

The reservoirs were not constructed for water quality enhancement; their authorized purposes were flood control, navigation, irrigation, and hydroelectric power generation (see Table 2). However, because of the hydrologic conditions in the Willamette Basin, the same influences that caused low-flow problems in the summer months also minimized the risk of summer floods and required significant releases of stored water for irrigation and navigation. This compatability between the authorized purposes, particularly navigation, and the need for more water in the river to enhance water quality has made possible an effective pollution control strategy--flow augmentation for waste dilution.

The plan for multi-purpose Federal storage reservoirs on the major tributaries of the Willamette River was conceived in the early 1930's. In the reports recommending authorization of individual projects, "water quality flow needs were recognized, and it was stated that the navigation flows of 6,000 cubic feet per second at Salem would provide for the water quality needs. Since that time, water quality management of the basin has been based upon the continued availability of those flows to meet navigation needs."[9] However, the Federal agencies involved in Willamette Basin water planning recognized, as had OSSA, that "the basic element of the water pollution control program is a high level of at-source waste treatment by all municipalities and industries."

The early Federal storage reservoirs in the Willamette Basin were comparatively small and had little effect on summer low-flow water quality. However, larger impoundments were completed starting in the early 1950's (see Figure 6) and the amount of storage water released to augment low natural flows began to have a noticeable effect thereafter. By 1968, 13 Federal projects were complete and providing flow augmentation benefits.

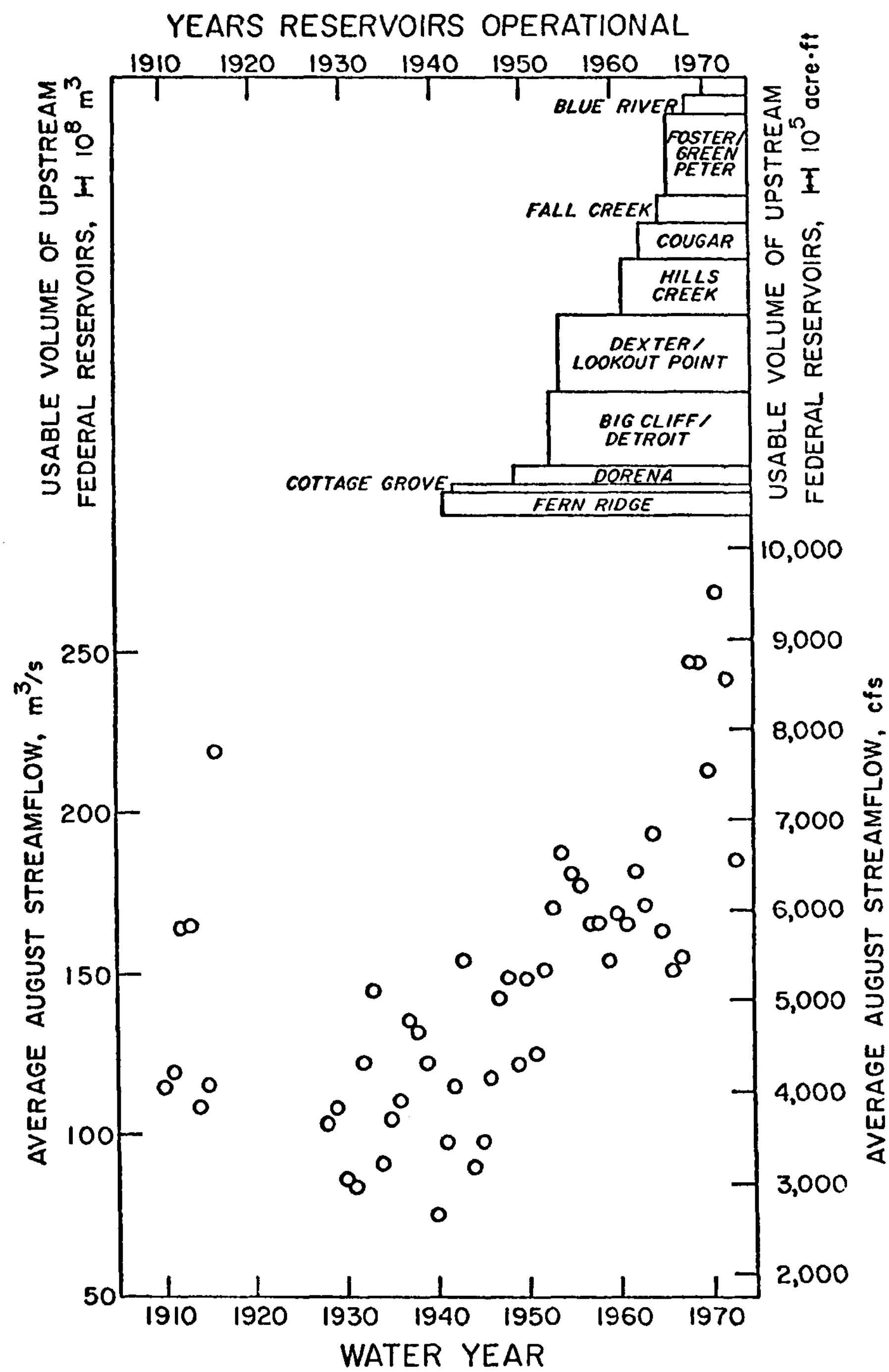

Figure 6. Average August streamflows at Salem and upstream federal reservoirs.

Using the dry month of August as a basis for comparison, average monthly discharge at Salem is shown in Figure 6 over the period of years of record. Allowing for year-to-year climatic variability, it is quite clear that impoundment releases in recent years have had a dramatic effect in increasing the amount of water in the river and in diluting wastes. In some years more than half of the August streamflow in the Willamette River has been from impoundment releases.

RELIANCE ON TWO STRATEGIES

The strategy adopted by the State of Oregon to set water quality standards and require compliance by means of at-source waste treatment *was absolutely essential and has been proven effective. The absolute* load of pollutants entering the Willamette River has been reduced and brought under control. This has also achieved a substantial change in the concentrations (i.e., relative amounts) of the various indicators of water quality, such as dissolved oxygen.

But during critical summer-autumn months of low natural streamflow, the measures taken to date to achieve at-source pollution control would not have been sufficient alone. The water quality standards have been met during some critical low-flow periods only because the river flow was substantially augmented from storage releases. In recent years, this augmented flow has been well above the target flows (e.g., above the $170m^3/s$ (6,000cfs) minimum flow at Salem). Therefore, it is evident that without more stringent requirements controlling the treatment of at-source pollution, the flow augmentation strategy is also essential. Data from recent years show that it has been an effective strategy.

In effect, there must presently be a reliance upon two pollution control strategies for the Willamette River: the first, guided and enforced by the State, requiring at-source waste treatment to reduce the absolute pollutant loadings; the second, under the control of the Federal government, requiring flow augmentation during critical low-flow months to reduce the concentration and strength of pollutant loadings. Jointly, these strategies allow the water quality standards of the State to be met. Without the first, at-source treatment, no practical amount of flow augmentation from existing multi-purpose reservoirs would be sufficient to allow the standards to be met. Without the second, flow augmentation, the degree of at-source waste removal would have to be greatly increased and new technologies beyond secondary treatment would be required.

SECTION VI

ENVIRONMENTAL IMPACTS

SCOPE OF IMPACTS

The cumulative environmental impacts of the pollution control strategies used for the Willamette River are broad and difficult to quantify. They touch human activities in a number of ways, some of which are describable collectively as altered quality of life, insofar as the Willamette River has an influence on an individual's interests and activities. For example, a recent study[16] showed that the substantial improvement of the Willamette River water quality led to increases in values for urban residential property as far as 1200 m (4000 ft) away from the water's edge. Interestingly, the wildlife support capacity of water bodies was valued more by residential property owners than were aesthetics, boating, or swimming. The measurable water quality parameters reported to have the greatest influence on property values were dissolved oxygen, fecal coliforms, clarity, trash and debris, toxic chemicals, and pH.

Some of the cumulative environmental impacts of at-source waste treatment are of a "trade-off" nature. The benefits gained by removal of contaminants from the water phase of the environment are offset by their disposal in some other phase of the environment. This can result in air pollution (through combustion of sludge or gases) and land pollution (through landfilling of residual sludges) which in turn can lead to water pollution. In-process changes made by some industries to reduce pollutant loads in effluents, such as the conversion of sulfite pulp-and-paper mills from one base to another to facilitate chemical recovery, have resulted in increased stack emissions from recovery boilers. Additional environmental contamination results from the production, transportation/transmission, and utilization of energy needed to drive all of the wastewater treatment processes and to produce the chemicals used in wastewater treatment. Such secondary impacts can cause significant environmental effects at locations distant from the treatment plants, often outside the Willamette Basin.

Wastewater treatment requires large tracts of land for the facilities themselves and for solid residue disposal; for municipalities this land represents a reduction in the tax base. In addition to odors and noise associated with the plant operation, some facilities are aesthetically displeasing. Adverse impacts such as those mentioned here must be weighed against the substantial benefits to river water quality evidenced by restored high oxygen levels and reductions in bacterial contamination, suspended solids, floating matter, and toxic chemicals.

Flow augmentation also has associated with it a number of trade-off environmental impacts. In downstream reaches below impoundments, the majority of impacts are regarded as beneficial, although the reduced summer temperatures of some releases and the diminished variability of flows can present adverse impacts such as less desirable swimming temperatures and less natural control over some aquatic vegetation and insects by periodic flooding. Improved navigation conditions can result in associated increases of boat-related forms of pollution. Greater flood control protection of the floodplain can lead to greater floodplain encroachment.

At the reservoirs and along adjacent reaches of the river, there may be additional environmental tradeoffs. Creation of a slack-water fishery and lake recreation is done at a loss of free-flowing fishery and stream recreation. Loss of one type of wildlife habitat is replaced by creation of a different type of habitat. Release of impounded water in the summer for flow augmentation represents a loss of impounded water needed for autumn hydroelectric power generation to supplement power produced elsewhere in the Columbia River Basin. This trade-off is partly offset by heavier reliance on non-power producing reservoirs such as Blue River and Fall Creek for summer flow augmentation. But impoundment releases for flow augmentation during the summer from additional non-power projects such as Dorena and Cottage Grove meets with greater resistance from recreationists using those reservoirs.

The "health" of a water body and extent of pollutional effects are often best reflected and measured by the performance of the bio-system. For the Willamette River, the part of the bio-system about which the most is known historically is the fishery, particularly the salmonid fishery. This anadromous fishery happens to be a particularly sensitive indicator of water quality conditions. Therefore, to document the cumulative environmental impacts of the pollution control strategies used for the Willamette River, detailed examination has been made of the Willamette River fishery.

HISTORICAL

The Willamette Basin undoubtedly was rich in certain natural resources prior to the 19th Century. Craig and Hacker[17] estimate that the Columbia Basin supported a population of 50,000 Indians who annually harvested 8 million kg (18 million lb) of salmon. Willamette Falls was identified as one of the historically famous Indian fishing sites.[18] Other wildlife forms such as cougar, river otter, muskrat, beaver, and migrating ducks and geese were thought to be more abundant before the year 1800 than at any subsequent time.

Commercial fishing for salmon began in the lower Columbia River region in the early 1800's. By 1830, several dealers were salt-curing salmon on the lower Willamette River for export.[19] Commercial canning of salmon began on the lower Columbia River in 1866 and increased rapidly to a record pack of 634,696 cases in 1895.[20] The record catch of salmon and steelhead occurred in 1911 when 21,117,000 kg (46,663,000 lb) were landed.[21]

In addition to salmon and steelhead, other Willamette fish harvested commercially were shad, sturgeon, eulachon (smelt) and lamprey. Of equal importance to the Willamette Basin were the recreational species and fisheries. Trout, primarily rainbow and cutthroat, were so abundant that the early bag limit was 125 fish per day. Warm-water game fishes such as largemouth and smallmouth bass, black and white crappie, bluegill, and pumpkinseed were introduced around the turn of the 19th Century and prospered in the sloughs and ponds of the Willamette Basin.[22]

During the 1800's, several wildlife species were affected by the activities of the early settlers. Logging and land-clearing benefitted the blacktailed deer, while mourning dove, band-tailed pigeon, ducks, and geese found the development of agriculture to their liking. Pheasants, valley quail, and bobwhite quail were introduced and increased rapidly. Other species were not so fortunate as the impact of unrestricted hunting and trapping severely reduced populations of beaver, river otter, and cougar.

Recognition of serious pollution in the lower Willamette River was a matter of public record as early as 1910 when Morse _et al._[23] stated in their Fourth Biennial Report of the State Board of Health that: "... they become a conduit into which in increasing quantities in direct proportion to the increasing density of the population, along their banks is cast offal and filth until nearly all of the streams of the State have become mere sewers, the water from which is not only dangerous to drink but too filthy in many places to bathe in. Even the very fish which have no means of escape are largely becoming infected and unfit for food. This condition is rapidly growing worse and has become a peril of no mean import, and is a grave reflection upon the intelligence and degree of civilization of the entire community and should be stopped at once and forever."

Subsequently, the so-called oxygen blockage in the lower Willamette River has been documented and studied repeatedly, as described earlier in this report. In particular, the reports by Gleeson[7] and Willis _et al._[24] are informative. The presence of water with oxygen levels below 5 mg/l for prolonged periods during July, August, and September, coupled with inadequate fish passage facilities at Willamette Falls, were believed to be important reasons why few coho salmon and fall chinook salmon occurred beyond the reaches of the lower Willamette River area.[24,25]

CURRENT STATUS OF THE WILLAMETTE FISHERY

The Willamette Basin contains from 14,000 to 16,000 km (9,000 to 10,000 mi) of streams, at least 565 named lakes, and approximately 130 mega square meters (Mm^2) (33,000 acres) of reservoirs.[19] Of this total, most production in fluvial habitats occurs in 6788 km (4219 mi) of streams comprising 196 Mm^2 (48,600 acres) of water. Stream widths greater than 100m (300 ft) comprise 10 percent of the length and 57 percent of the total surface area; whereas, streams less than 1 m (4 ft) in width comprise 27 percent of the length but only 1.1 percent of the surface area.[26]

Some 51 species belonging to 14 families comprise the fish fauna of the Willamette Basin. At least 28 species are of recreational or commercial importance. Almost one-half of the species (23) have been introduced into the basin during the past 100 years (see Table 5). Distributions of the salmonids and some of the warm-water game fishes within their principal habitats in the Willamette Basin are provided in Tables 6, 7, and 8.

Several recent reports give detailed descriptions of the current status of the fishery and wildlife resources of the Willamette Basin. One of the most extensive and detailed surveys of the Willamette River and its tributaries was conducted by Willis et al.[24] Their report includes the following information on each river system: a brief introduction; descriptive information concerning the basin, stream, bottom material, obstructions, diversions, and pollution problems; impoundment and hatchery sites; temperature and flow data; anadromous fish populations; and major proposed dams. A summary of recommendations was presented for the entire Willamette River system wherein the proposed projects were listed in order of priority or importance without reference to costs or estimates or responsibility.

More recently details of the middle Willamette Basin were provided by the Oregon State Game Commission; those of the lower Willamette Basin were provided by Hutchison and Aney[28]; while those of the upper Willamette Basin were detailed by Hutchison et al.[29] Thompson et al.[27] combined much of the information on fishery resources from the above three reports into "Fish Resources of the Willamette Basin", which was submitted to the Willamette Basin Task Force. In turn, the information provided by the above four sources was combined and published as Appendix D, Fish and Wildlife, to the Willamette Basin Comprehensive Study of Water and Related Land Resources.[19]

A more generalized review of the fish and wildlife resources of the Willamette River watershed, including the Sandy River watershed, was published as Appendix XIV, Fish and Wildlife, to the Comprehensive Framework Study of Water and Related Lands.[30] This latter report contains useful information on fish and wildlife Angler-Days and Hunter-Days

Table 5. FISHES OF THE WILLAMETTE BASIN[a]

Scientific name	Common name	Abundance
Petromyzontidae		
Entosphenus tridentata	Pacific lamprey	High
Lampetra richardsoni	Western brook lamprey	High
Acipenseridae		
Acipenser transmontanus[b]	White sturgeon	Moderate
Clupeidae		
Alosa sapidissima[b,c]	American shad	High below Willamette Falls; low above falls
Salmonidae		
Oncorhynchus keta[b]	Chum salmon	Low
Oncorhynchus kisutch[b]	Coho salmon	Moderate
Oncorhynchus nerka[b,c]	Sockeye salmon or kokanee	Low
Oncorhynchus tshawytscha[b]	Spring chinook and Fall chinook salmon	Moderate to high Moderate
Prosopium williamsoni[b]	Mountain whitefish	Low to moderate
Salmo aguabonita[b,c]	Golden trout	Low
Salmo clarki[b]	Cutthroat trout	High
Salmo gairdneri[b]	Rainbow (steelhead) trout	Moderate
Salmo salar[b,c]	Atlantic salmon	Low
Salmo trutta[b,c]	Brown trout	Low
Salvelinus fontinalis[b,c]	Brook trout	Low
Salvelinus malma[b]	Dolly Varden	Low
Salvelinus namaycush[b,c]	Lake trout	Low

Table 5 (continued). FISHES OF THE WILLAMETTE BASIN[a]

Scientific name	Common name	Abundance
Cyprinidae		
Acrocheilus alutaceus	Chiselmouth	High
Carassius auratus[c]	Goldfish	Low
Cyprinus carpio[c]	Carp	High
Hybopsis crameri	Oregon chub	Low
Mylocheilus caurinus	Peamouth	Moderate
Ptychocheilus oregonensis	Northern squawfish	High
Rhinichthys cataractae	Longnose dace	High
Rhinichthys falcatus	Leopard dace	High
Rhinichthys osculus	Speckled dace	High
Richardsonius balteatus	Redside shiner	High
Tinca tinca[c]	Tench	Low
Catostomidae		
Catostomus macrocheilus	Largescale sucker	High
Catostomus platyrhynchus	Mountain sucker	High above Corvallis; low in downstream areas
Ictaluridae		
Ictalurus melas[b,c]	Black bullhead	(Unauthenticated reports)
Ictalurus natalis[b,c]	Yellow bullhead	Moderate
Ictalurus nebulosus[b,c]	Brown bullhead	Moderate
Ictalurus punctatus[b,c]	Channel catfish	Low to moderate
Percopsidae		
Percopsis transmontana	Sand roller	Low to moderate
Poeciliidae		
Gambusia affinis[c]	Mosquitofish	Low to moderate

Table 5 (continued). FISHES OF THE WILLAMETTE BASIN[a]

Scientific name	Common name	Abundance
Gasterosteidae		
Gasterosteus aculeatus	Threespine stickleback	High
Centrarchidae		
Lepomis gibbosus[b,c]	Pumpkinseed	High
Lepomis gulosus[b,c]	Warmouth	High
Lepomis macrochirus[b,c]	Bluegill	High
Micropterus dolomieui[b,c]	Smallmouth bass	Moderate
Micropterus salmoides[b,c]	Largemouth bass	High
Pomoxis annularis[b,c]	White crappie	High
Pomoxis nigromaculatus[b,c]	Black crappie	High
Percidae		
Perca flavescens[b,c]	Yellow perch	High
Cottidae		
Cottus asper	Prickly sculpin	Low
Cottus bairdi	Mottled sculpin	Low
Cottus beldingi	Piute sculpin	Moderate
Cottus perplexus	Reticulate sculpin	Moderate
Cottus rhotheus	Torrent sculpin	Low

[a] Modified from reference 27.

[b] Species defined as "game fish" in the 1965-66 Oregon Game Code.

[c] Introduced species, all others are indigenous to the Willamette Basin.

Table 6. DISTRIBUTION OF PRINCIPAL SALMONIDS INHABITING LAKES, RESERVOIRS, SLOUGHS, OR PONDS IN THE WILLAMETTE BASIN[a]

Species	Number of lakes inhabited[b]	Surface area, 1000 m^2,[c] inhabited[d]	Hatchery contribution,[e] percent
Brook trout	34	15,870	50
Cutthroat trout	37	68,696	11
Dolly Varden trout	8	8,101	0
Kokanee	13	14,090	77
Lake trout	0	0	0
Rainbow trout	48	70,177	92
Chinook salmon (L)[f]	13	34,864	62
Coho salmon (L)[f]	8	11,600	100
Steelhead (L)[f]	9	10,170	33

[a] Data from reference 26.

[b] 78 lakes available.

[c] 1000m^2 = 0.247 acres.

[d] 78,489,000 m^2 available.

[e] Percent of lakes in which any portion of species are of hatchery origin.

[f] L indicates Landlocked populations only.

Table 7. DISTRIBUTION OF PRINCIPAL ANADROMOUS SALMONIDS INHABITING RIVERS AND STREAMS IN THE WILLAMETTE BASIN[a]

Species	Streams inhabited[b]	Stream length, km,[c] inhabited[d]	Estimated population
Fall chinook salmon	41	1,150	7,600
Spring chinook salmon	64	2,016	34,000
Coho salmon	147	3,313	17,000
Summer steelhead	33	1,130	660
Winter steelhead	127	3,181	16,000
Sockeye salmon	17	553	200
Sea-run cutthroat trout	31	677	68

[a] Data from reference 26.

[b] 290 streams available.

[c] 1 km = 0.621 mi.

[d] 6,668 km available.

Table 8. DISTRIBUTION OF CERTAIN WARM-WATER GAME FISH INHABITING RIVERS AND STREAMS IN THE WILLAMETTE BASIN[a]

Species	Streams inhabited[b]	Stream length, km,[c] inhabited[d]	Abundance
Black crappie	12	351	Common
White crappie	36	938	Few
Largemouth bass	39	912	Few/rare
Smallmouth bass	2	61	Rare

[a] Data from reference 26.

[b] 290 streams available.

[c] 1 km = 0.621 mi.

[d] 6,668 km available.

which are summarized in Table 9. Information is also provided on non-game wildlife along with projections of future needs to satisfy the demand for use of fish and wildlife resources within the Willamette Basin.

In summarizing the current status of the resource, it appears that stocks of spring chinook salmon have stabilized at 30,000 to 40,000 escapements over Willamette Falls. Stocks of spring chinook salmon returning to the Clackamas River appear to have decreased in recent times from about 3,000 to 2,000 fish per year (Figure 7). Based on an average fecundity of 5,000 eggs and a 50:50 sex ratio, the Clackamas River run must have contained a minimum of 6,000 fish around the turn of the century. The runs of spring chinook salmon are heavily supported with releases from hatcheries.

Escapements of coho salmon past Willamette Falls have decreased markedly in the past four years (Figure 8). On the other hand, escapements of fall chinook salmon (Figure 8) and summer and winter steelhead (Figure 9) are all on the increase. Overall, the sport catch of salmon and steelhead in the Willamette Basin is on the increase as well as in the State as a whole (Figures 10,11).

Overall, stocks of resident trout appear to be greatly reduced from earlier years, but liberal supplements with hatchery fish help maintain heavy angler use (Table 9). Virtually no stocking of warm-water game fish is carried out as natural stocks seem sufficient for substantial angler use (Table 9).

ENVIRONMENTAL IMPACTS

Benefits

Anadromous fish resources are obvious beneficiaries of water quality improvements in the lower Willamette River. Waters with less than 5 mg/l of dissolved oxygen are generally thought to block or delay the passage of migrating salmonids.[7] Sams and Conover[25] presented data indicating that runs of coho and fall chinook salmon did not attempt to pass over Willamette Falls until dissolved oxygen levels exceeded 4 mg/l. Based on data depicted in Figures 12 and 13, the lower 50 miles of the Willamette River apparently served as an oxygen blockage to migrating salmon during much of July, August, and September from the 1920's to 1968. From 1968 to present, the mean dissolved oxygen concentration during the critical month of August was never below 5 mg/l at the Spokane, Portland and Seattle Railroad bridge--an area thought to be one of the most seriously polluted sections of the River. Whether the increase in dissolved oxygen was due to municipal and industrial waste treatment or to augmented flow of the River is a matter of conjecture (Figure 13).

Table 9. ESTIMATED USER-DAYS FOR CERTAIN FISH AND WILDLIFE SPECIES IN THE WILLAMETTE BASIN: 1965[a].

Resource	Species	User-days	Value of resource, dollars
Fish	Stream fish	735,300	
	Lake and pond fish	19,900	
	Reservoir fish	238,500	5,000,000
Big game	Deer	310,000	
	Elk	8,000	
	Black bear	6,000	
	Mountain lion	2,000	3,000,000
Upland game	Pheasant	182,500	
	Quail	55,000	
	Grouse	16,600	
	Mourning dove	35,600	
	Band-tailed pigeon	25,900	
	Rabbit	15,000	
	Squirrel	6,400	1,500,000
Waterfowl	Ducks	84,800	
	Geese	26,400	700,000
TOTAL		1,767,900	10,260,000[b]

[a] Estimates based on Oregon State Game Commission data and adapted from reference 30.

[b] Includes $60,000 as value of pelts from furbearing animals.

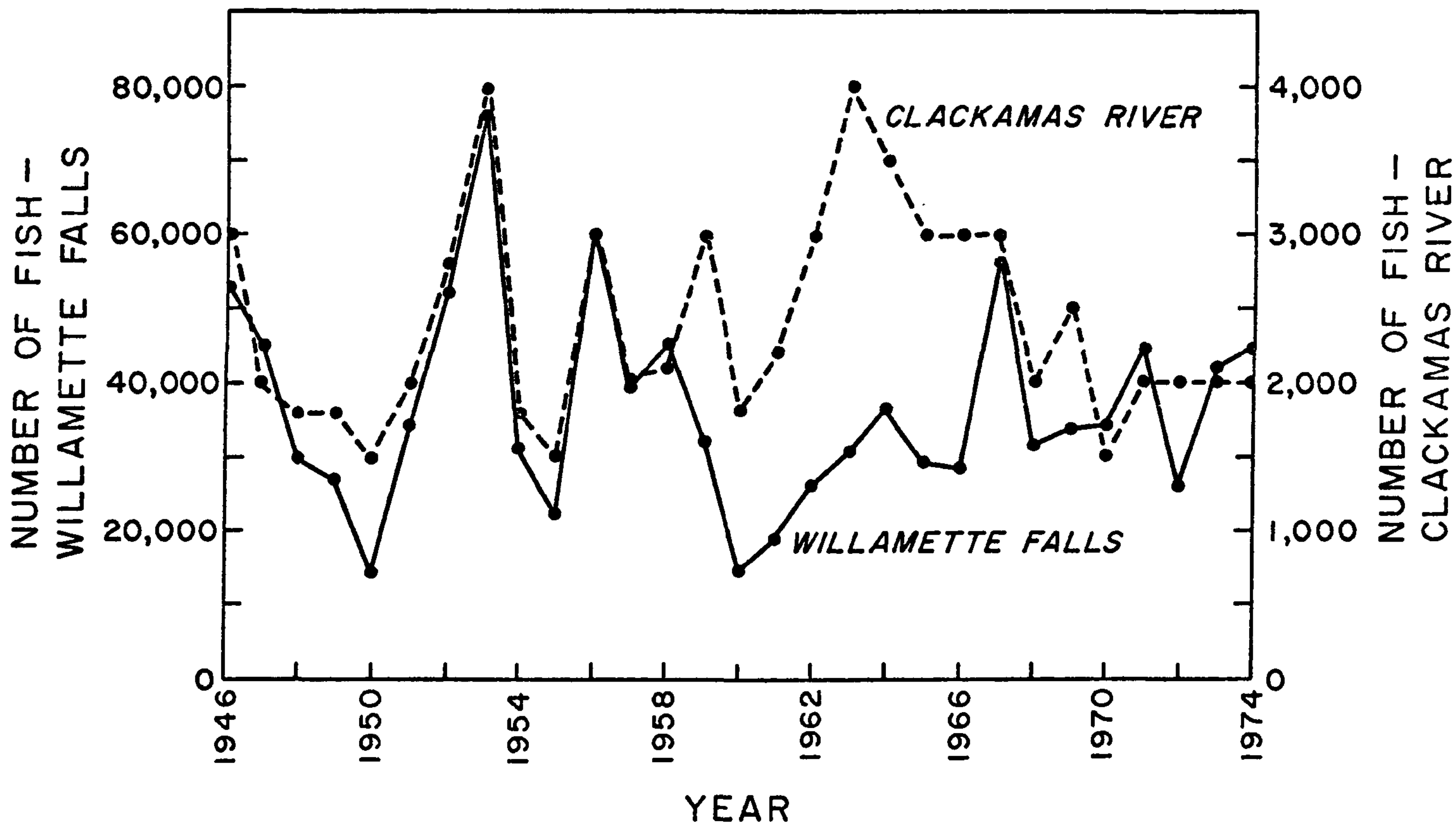

Figure 7. Calculated escapement of spring chinook salmon into the Clackamas River compared to the total migration of spring chinook salmon over Willamette Falls: 1946-1974.[31,32]

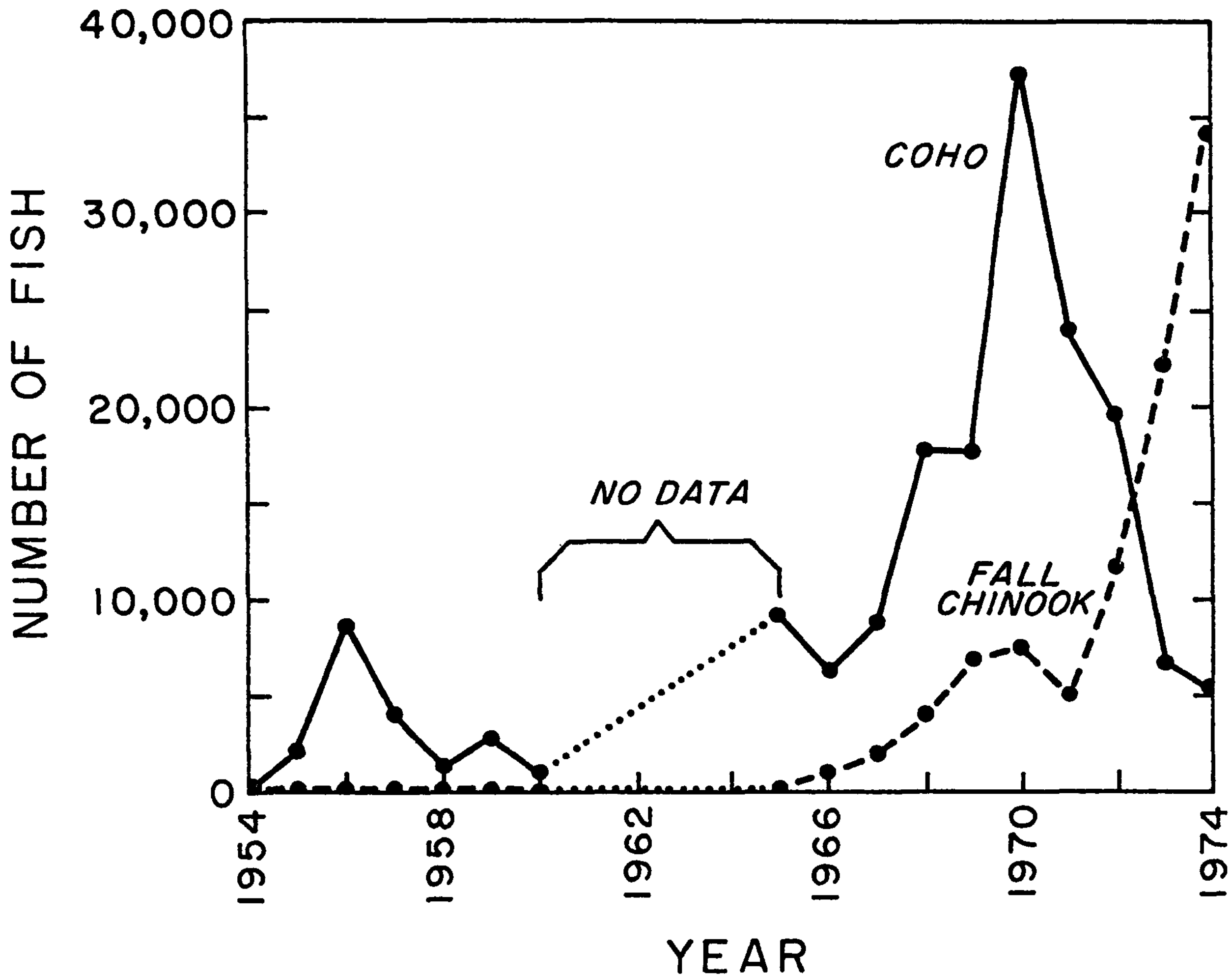

Figure 8. Calculated migration of coho and fall chinook salmon over Willamette Falls: 1954-1974[31,32]

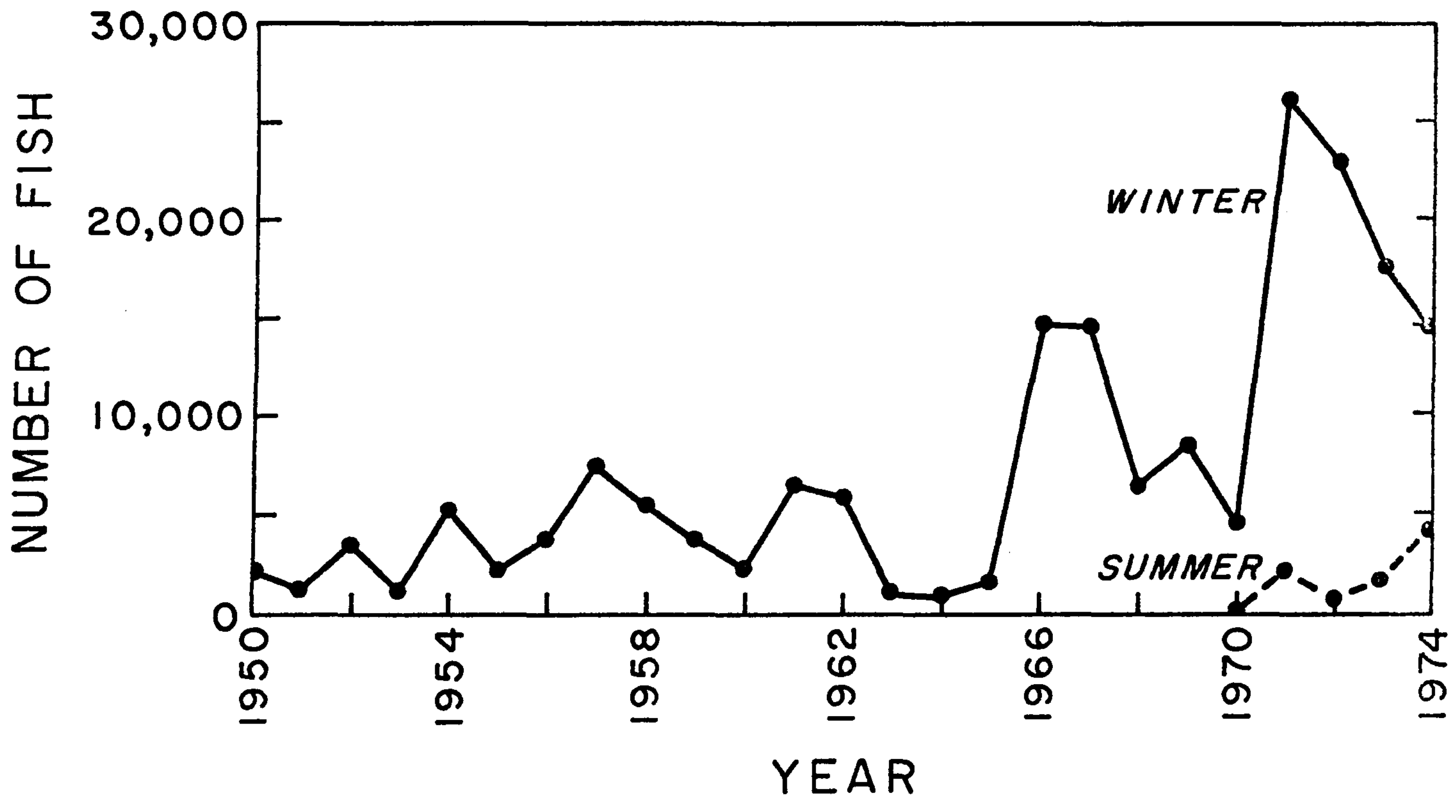

Figure 9. Calculated migration of winter and summer steelhead over Willamette Falls: 1950-1974.[31,32]

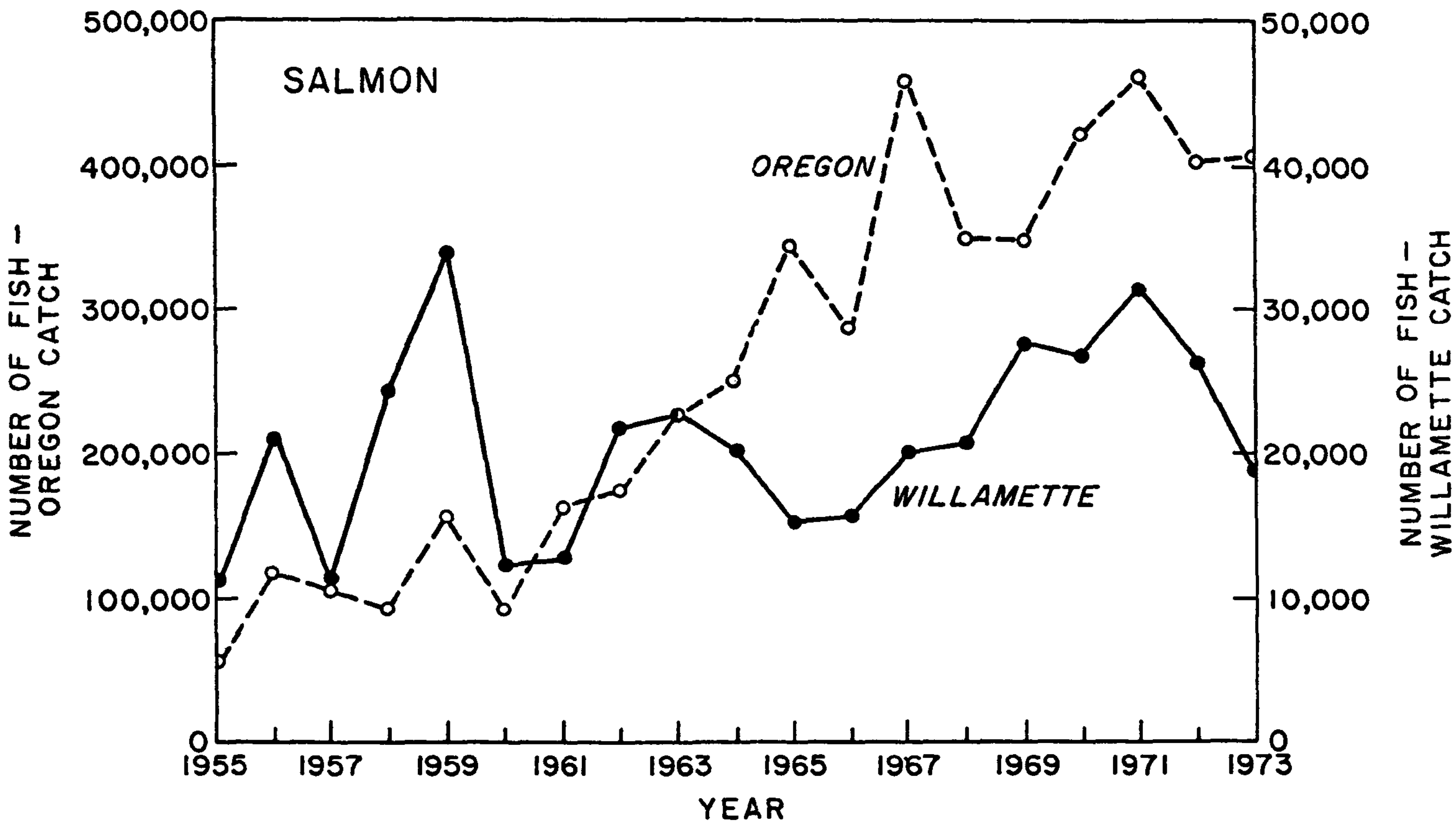

Figure 10. Estimated total sport catch of salmon in Oregon compared to the estimated sport catch of salmon from principal Willamette River tributaries: 1955-1973.[33]

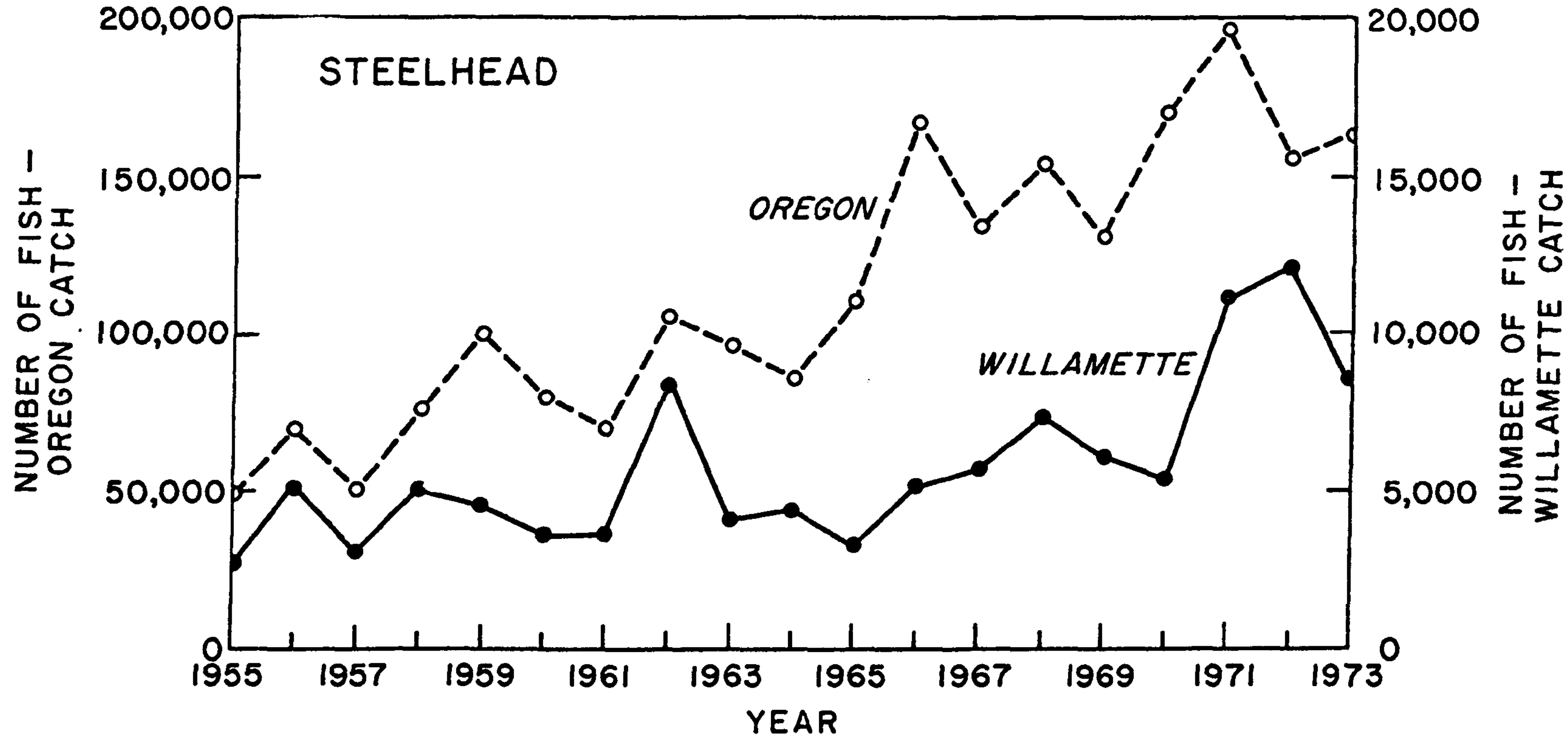

Figure 11. Estimated total sport catch of steelhead in Oregon compared to the estimated sport catch of steelhead from principal Willamette River tributaries: 1955-1973.[33]

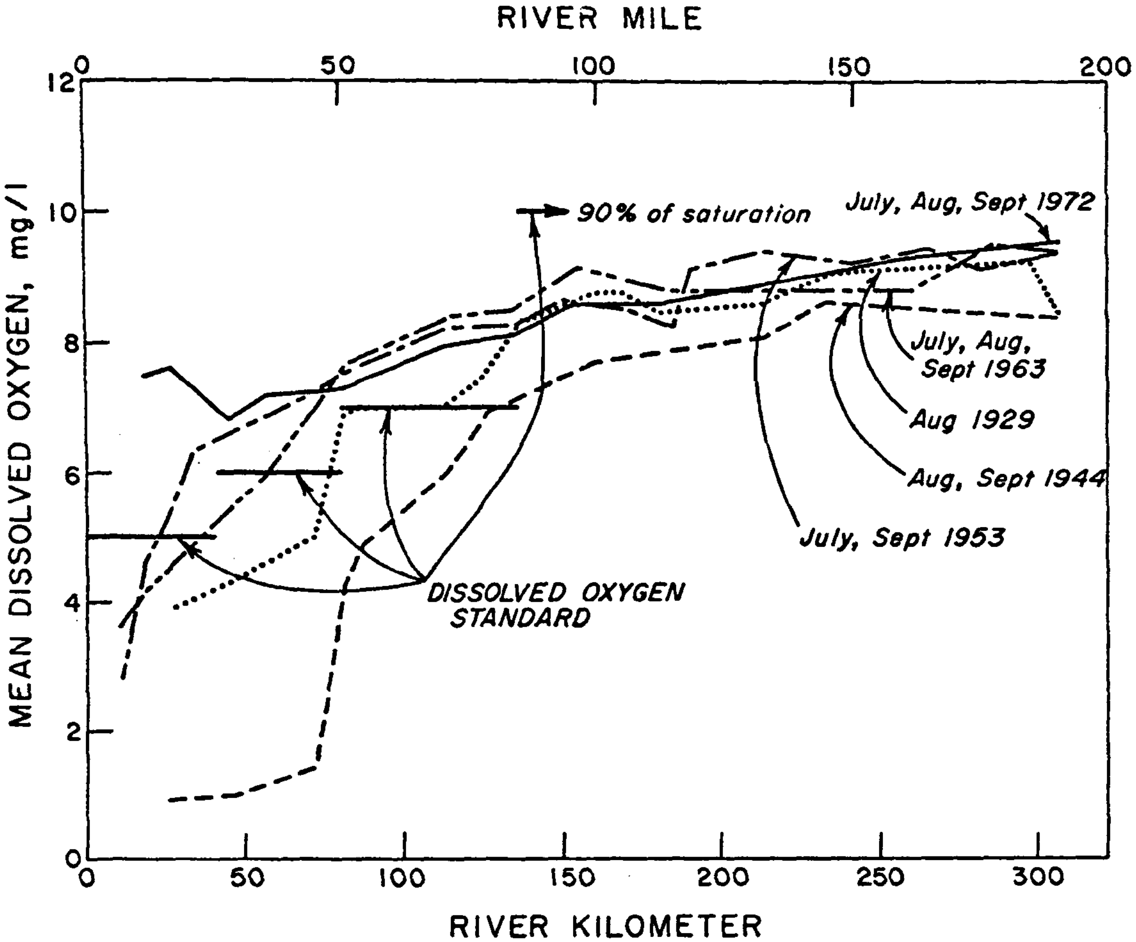

Figure 12. Mean dissolved oxygen concentrations for summer months in the Willamette River at selected locations and years.

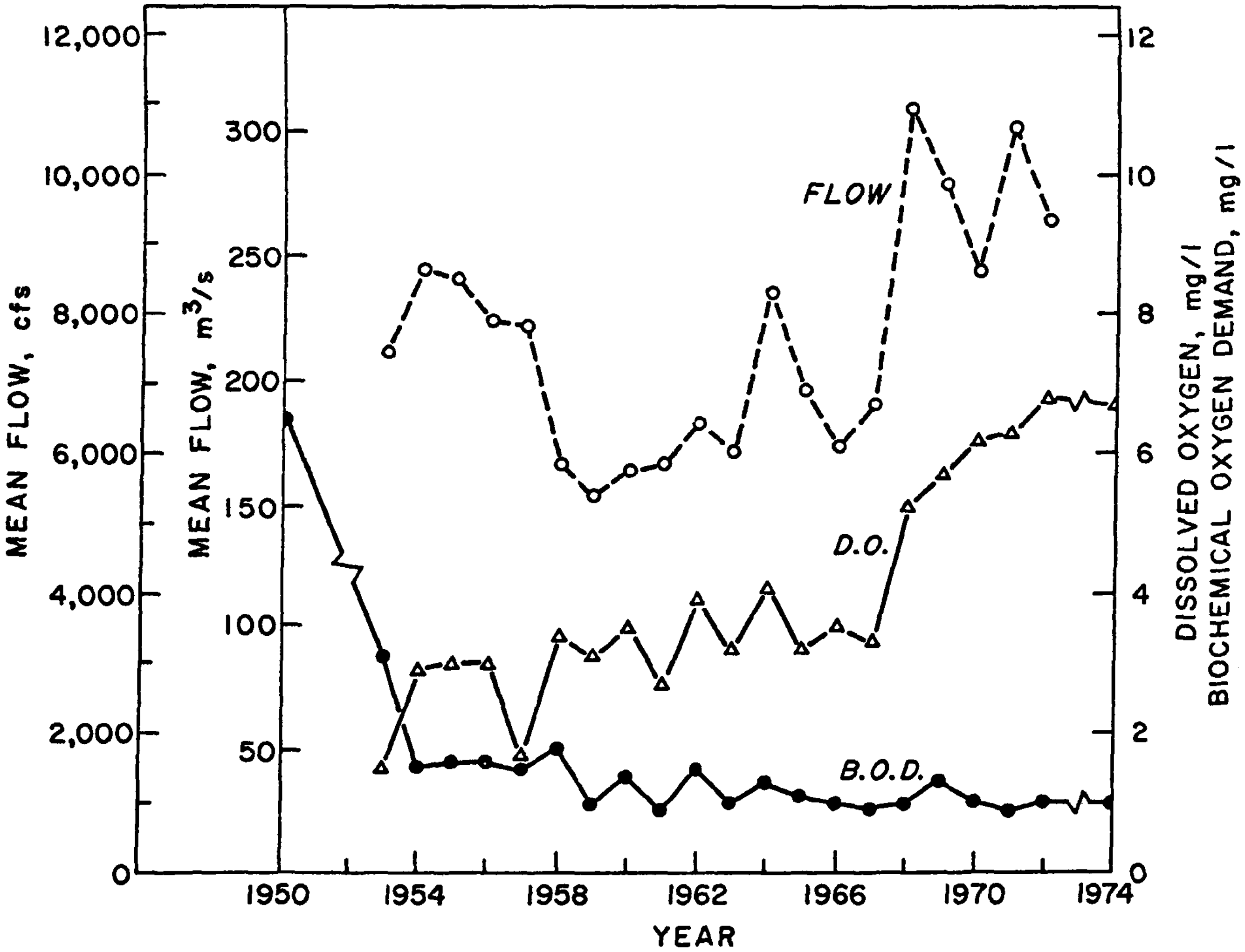

Figure 13. Mean flow, dissolved oxygen concentration, and 5-day biochemical oxygen demand of the lower Willamette River at the Spokane, Portland, and Seattle Railroad bridge during August 1950-1974.[34]

Undoubtedly both activities were instrumental in helping to improve the oxygen concentration.

With the prospects of continued improvement in water quality and the completion of vastly improved fish passage facilities at Willamette Falls, the Fish Commission of Oregon initiated a 9-year plan to fully develop the salmon and steelhead potential of the Willamette River. The plan was first made public in 1969[35] and was formally developed in 1970[35]. The individual and combined annual benefits to Oregon from full development of the potential in the Willamette River for self-sustained natural production of fall chinook and coho salmon and summer and winter steelhead are presented in Table 10. In fiscal 1971, the plan was implemented and jointly funded by the National Marine Fisheries Service and the Fish Commission of Oregon.[36,37] Data contained in Figures 8 and 9 indicate that the fall chinook salmon and summer steelhead programs have been highly successful to date. Winter steelhead show definite increases over the past ten years, while coho salmon decreased in abundance during the past two years. The decreases in coho are not surprising in view of similar drops in production throughout the northwest, indicating a problem in the oceanic environment rather than in their nursery and rearing areas.

Values for temperature and pH have been little affected by water pollution control, and apparently have had little influence on the migratory patterns of anadromous salmonids. Sams and Conover[25] reported that temperatures as high as 23°C (73°F) did not prevent salmon from entering the Willamette River from cooler water in the Columbia River. Not since 1958 has the August mean temperature been higher than 23°C (73°F) at the Spokane, Portland and Seattle Railroad bridge. Also, the increased flow pattern since 1968 does not appear to be associated with any general change in temperature at the same location. Likewise, pH has remained at 6.7 - 6.9 during the last 20 years.

Recreational use of the Willamette River and its immediate environment has been increasing, and based on data collected in 1970 is predicted to double in 20 years (by 1990). For example, in 1970 anglers participated in 603,000 recreational-days while catching 759,000 fish. By 1990, the number of recreational-days devoted to angling in the Willamette Basin is predicted to increase to 1,410,000.[26] Personnel of the Oregon State Highway Division estimated that swimming, water skiing, boating, and other water-related activities accounted for 8,000,000 activity-days in the Willamette River during 1970. This number is projected to increase to 16,000,000 by the year 1990.[38] Use of State parks on the Willamette River has increased from 398,000 to 627,000 visitor-days during the period 1969-70 to 1973-74, respectively.[37] Certainly all the increased use of the Willamette River and its related environments cannot directly be attributed to aquatic pollution abatement. It would equally be unjust to maintain that quality of the River has no effect on recreational use.

Table 10. BENEFITS TO OREGON OF FULL DEVELOPMENT OF THE POTENTIAL IN THE WILLAMETTE RIVER FOR SELF-SUSTAINED NATURAL PRODUCTION OF FALL CHINOOK AND COHO SALMON AND SUMMER AND WINTER STEELHEAD[a]

Species	Fishery	Benefit[b]	Present status	Potential for increase	Total potential
Fall chinook salmon	Commercial	Number of fish	3,000	72,000	75,000
		Processed value[c]	$ 28,000	$ 675,000	$ 703,000
	Sport[d]	Number of fish	600	15,000	15,600
		Gross economic value	$ 6,000	$ 150,000	$ 156,000
		Number of angler-days	600	15,000	15,600
Coho salmon	Commercial	Number of fish	20,000	45,000	65,000
		Processed value	$ 80,000	$ 180,000	$ 260,000
	Sport	Number of fish	7,000	15,000	22,000
		Gross economic value	$ 90,000	$ 200,000	$ 290,000
		Number of angler-days	9,000	20,000	29,000
Summer steelhead	Commercial	Number of fish		3,000	3,000
		Processed value		$ 10,000	$ 10,000
	Sport	Number of fish		25,000	25,000
		Gross economic value		$1,000,000	$1,000,000
		Number of angler-days		100,000	100,000
Winter steelhead	Commercial	Number of fish	1,000	1,500	2,500
		Processed value	$ 6,000	$ 8,000	$ 14,000
	Sport	Number of fish	3,200	4,400	7,600
		Gross economic value	$125,000	$ 175,000	$ 300,000
		Number of angler-days	12,500	17,500	30,000

Total potential increase in numbers	180,900
Total potential increase in value	$2,398,000
Total potential increase in angler-days	152,500

[a] Modified from reference 35.

[b] This does not include hatchery production or potential production in reservoirs or in streams above impassable dams, falls, or other barriers to upstream migrant adults.

[c] Based on 1968 prices.

[d] Total expenditures by sport fishermen, but excluding the cost of fishing licenses and salmon steelhead punch cards. Based on 1962 dollars.

Augmented summer flows have been beneficial to resident trout populations. The increased flows provide greater feeding and breeding areas, as well as help maintain stream temperatures at a more favorable level. Another benefit of cooler water has been the reduction in production of so-called "trash fish". In addition, control of flooding has decreased entrapment of salmonids in flood plain potholes.

A particularly significant demonstration of the cumulative beneficial environmental impacts of pollution control and water quality restoration is the so-called Willamette Greenway plan. The plan was conceived in 1966, at a time when the recovery of Willamette River water quality could be seen to be attainable in the near future, and called for a Willamette River Park System. A law was enacted in 1967 "to protect and preserve for present and future generations...the natural scenic and recreational value of the Willamette River" by establishing riverbank parks along the Willamette. Recreational use of the River has greatly increased since 1966, particularly by kayak, canoe and waterski enthusiasts. The Greenway plan represents a sizeable financial commitment by the State (with some Federal matching funds) to protect the re-established recreational, fishery and wildlife values which have resulted from the pollution control strategies utilized to date. The Greenway is both a commitment and a statement of faith to the future protection of the recovered water quality in the Willamette River.

Adverse Effects

At least 190 km (120 mi) of free-flowing streams have been inundated by reservoirs whose naked and muddy banks are regularly exposed by annual draw-downs.[40] The aesthetic loss of such natural habitats on principal tributaries to the Willamette River cannot adequately be replaced by any type of mitigation. Coomber and Biswas[41] quoting Starker Leopold point out that, "For things society judges to be desirable, relative scarcity or uniqueness increases value to society."

"In Western Oregon, water impoundments are detrimental to big game. Key winter ranges and migration routes normally coincide with reservoir sites. Game population densities relying on these lowland stream bottom areas commonly are several times the densities occurring elsewhere. The seasonal, altitudinal migrations of deer and elk along streams have been blocked by the construction of impoundments and has caused them to remain at high elevations during the winter.[29] Populations of furbearing animals which normally thrive in the flood plain have adversely been effected by flood control. Likewise, populations of ducks which formerly nested in flood plain potholes have been effected.

Turbidity, especially in Hills Creek Reservoir, has been identified as a biological, aesthetic and economic problem involving problems with fish and wildlife, recreation, and other uses of the impoundment.[42]

These authors speculated that low quantities of organic matter, which adversely effect basic productivity, may indeed be related indirectly to the turbidity of the water.

Chlorination of municipal wastewaters is the cheapest and most effective general method of wastewater disinfection in the United States. Generally recommended concentrations for residual chlorine are between 0.5 and 1.0 mg/l.[43] Chlorine, however, is an extremely powerful biocide and a major toxicant in sewage which eliminates pathogens but also damages fish and other aquatic organisms. The presence of chlorine below sewage outfalls is often noticeable by odor and by degradation of living stream bed organisms.[44]

Although fish are repelled by low levels of chlorine in water and frequently can escape in time, other aquatic organisms in the food chain may be eliminated. Brungs,[43] in Table 11, shows acute and chronic effects of residual chlorine on aquatic life.

The Oregon DEQ requires residual chlorine levels of 1 mg/l to ensure that fecal coliforms levels are maintained below 200 organisms/100 milliliters (ml). Many wastewater treatment plant operators, probably operating on the assumption that if a little chlorine is good a lot is great, overchlorinate. Monthly averages of residual chlorine in treatment plant effluents as high as 9 mg/l have been recorded. Proper surveillance of disinfection practices and increased operator education regarding both the positive and negative aspects of chlorination could mitigate this problem.

Summary

The net environmental impacts of the Willamette River cleanup are wide ranging. The effects of the restoration on some fish and wildlife species have been briefly described here; but obviously many other effects--biological, physical, aesthetic--which deny quantification have not been dealt with.

The impacts of water quality control programs extend far beyond the water phase of our environment. Many aspects, such as transportation, land use, and air quality, are involved in water quality management and these parameters must also be considered so that the net impact of environmental protection plans is a positive one.

Table 11. SELECTED SUMMARY OF ACUTE AND CHRONIC TOXIC EFFECTS OF RESIDUAL CHLORINE ON AQUATIC LIFE[a]

Species	Effect endpoint	Measured residual chlorine concentration, (mg/l)
Coho salmon	7-day TL_{50}[b]	0.083
Pink salmon	100% kill (1-2 days)	0.08-0.10
Coho salmon	100% kill (1-2 days)	0.13-0.20
Pink salmon	Maximum nonlethal	0.05
Coho salmon	Maximum nonlethal	0.05
Brook trout	7-day TL_{50}[b]	0.083
Brook trout	Absent in streams	0.015
Brown trout	Absent in streams	0.015
Brook trout	67% lethality (4 days)	0.01
Brook trout	Depressed activity	0.005
Rainbow trout	96-hour TL_{50}[b]	0.14-0.29
Rainbow trout	7-day TL_{50}[b]	0.08
Rainbow trout	Lethal (12 days)	0.01
Trout fry	Lethal (2 days)	0.06
Yellow perch	7-day TL_{50}[b]	0.205
Largemouth bass	7-day TL_{50}[b]	0.261
Smallmouth bass	Absent in streams	0.1
White sucker	7-day TL_{50}[b]	0.132
Walleye	7-day TL_{50}[b]	0.15
Black bullhead	96-hour TL_{50}[b]	0.099
Fathead minnow	96-hour TL_{50}[b]	0.05-0.16
Fathead minnow	7-day TL_{50}[b]	0.082-0.115
Fathead minnow	Safe concentration	0.0165
Golden shiner	96-hour TL_{50}[b]	0.19
Fish species diversity	50% reduction	0.01
Scud	Safe concentration	0.0034
Scud	Safe concentration	0.012
Daphnia magna	Safe concentration	0.003
Protozoa	Lethal	0.01

[a] Adapted from reference 43.

[b] TL_{50} = median tolerance limit (50 percent survival).

SECTION VII

CAPITAL EXPENDITURES

INTRODUCTION

The objectives of this research contract included documenting the dollar and energy costs of constructing the pollution control facilities that have contributed to the cleanup of the Willamette River. In the early stages of the investigation, limitations were established on facilities and expenditures to be researched. Investigation of three major subject areas was undertaken.

One subject area was municipal wastewater collection, treatment, and release dealing mainly with domestic wastes but also including large quantities of industrial wastes handled by municipal systems. It was agreed among project members and EPA representatives to limit "collection" to those portions of sewerage systems designated as "interceptors". This was done for a number of reasons. Interceptors make up that portion of the system which prevents flows from the sewers, laterals, and trunks from passing untreated into the receiving water and generally convey the flows "downstream" to the treatment plant. The Federal government's financial participation in water pollution abatement is generally limited to interceptors, treatment works, and outfalls and excludes portions above or "upstream" of interceptors. Also, reported expenditure data generally followed the above definitions. Municipal wastewater "treatment" included treatment works as well as the treating and disposing of associated sludges. "Release" covered outfall and diffuser works at the plant and at upstream overflow points.

The second subject area involved industrial water pollution abatement. This included the collection, treatment, and disposal of various waste streams, as well as in-process modifications reducing, concentrating, or eliminating certain wastewaters.

The final subject area investigated was reservoirs. This part of the research was confined to the thirteen Corps of Engineers' impoundments as it was felt that smaller, private industry or utility dams had relatively negligible downstream water quality impacts.

Limitations were also set as to what type of expenditures at these facilities would be investigated. Construction costs (economic and energetic) were researched in depth. Design costs of municipal systems were estimated; these figures are included in the capital cost table appended to this report. Lands costs were not considered. All cost adjustments were made using the Construction Cost Index published in the "Engineering News Record".

At this point it would be well to mention certain types of expenditures which have been omitted from analysis. First, under municipal systems, no portions of the collection system above interceptors have been investigated (although some parts may have entered the picture either by a misunderstanding by municipal officials of the definition of the word "interceptor" or in those cases where a reported construction award amount was for a joint project, e.g., interceptors and trunks). Second, for industrial activities, many small firms were eliminated from the research. The reasons for that are discussed in subsequent paragraphs. A third omission is that of the energy costs of engineering services. Finally, the costs of administrative actions by federal, state, and local regulatory agencies have not been taken into account.

INVENTORY OF FACILITIES

Table 12 is a list of municipal wastewater treatment plants operating in the Willamette Valley. The table includes information regarding plant type, the year each was put in operation or underwent its last major expansion or addition, design capacity in terms of population equivalents and flow, and location of discharge point. Table 13 is a compilation of those plants from Table 12 having significant industrial or commercial flow contributions.

Table 14 presents information similar to that in Table 12 for domestic sewage treatment plants which have been abandoned. Most of these plants were abandoned in favor of larger regional plants and the new receiving plant is named if known. Several points should be made here. First, while the approximately seventy abandoned plants seem significant when compared to the one-hundred thirty or so currently operating plants, their capital costs represent less than two percent of all treatment plant capital costs. Secondly, the short period of operation at many of these plants should be noted. Most operated less than ten years and many for less than five. While these plants represent a small portion of the total, they do represent a lack of full lifetime utilization. Finally, it should also be made clear that these lists are by no means firm. New plants are under construction and many existing plants will be phased out within the next decade.

Table 15 is a list of the twenty largest industries having their own treatment works. Thirteen have waste streams which are organic in nature (e.g., the pulp and/or paper manufacturers) while seven have inorganic wastes (e.g., the metal producers). The reader should be aware that many more industries are located in the Willamette Valley. These include companies having their own treatment facilities and outfalls (e.g., many sawmills and plywood and veneer operations) as well as those firms which discharge to municipal systems (e.g., many food processors), possibly following some degree of pretreatment. The

Table 12. OPERATING MUNICIPAL SEWAGE TREATMENT PLANTS

Plant	Type[a]	Year built	Design domestic population equivalent	Design m^3/day[b]	Receiving stream river kilometer[a,c]
Adair	TF	1959	750	760	Sl to Willamette
Albany	AS	1969	40,700	33,000	Willamette-191.5
Aloha	AL-EF	1973	40,000	15,000	Beaverton Cr.-5.3
American Can Co.	AL	1969	310	120	Willamette-238.8
Amity	L	1968	1,000	380	Ash Swale Cr.-2.4
AP Industrial Park	EA-L	1969	75	30	Columbia Sl
Aumsville	L	1971	1,660	630	Beaver Cr.-4.0
Banks	EA	1936 1967	1,050	530	W. Fk. Dairy Ck.-16.1
Beaverton	TF-EF	1963	14,000	6,100	Beaverton Cr.-12.9
Brownsville	L	1965	1,290	490	Calapooia-50.8
Burright Subdivision	EA	1964	90	34	Mitchell Cr.
Canby	AS	1971	6,000	3,200	Willamette-53.1
Carlton	TF	1955	1,500	1,100	N Yamhill-9.7
Cedar Hills	TF	1962	13,000	4,900	Beaverton Cr.-12.1
Central Linn H.S.	EA	1958	100	30	Spoon Cr.-7.1
Century Meadows	EA	1972	400	150	Willamette-67.6
Chatnicka Heights	EA	1964	400	150	Glenn Cr. to Winslow Cr.-7.2
Chemewa Indian School	AL	1965	1,450	550	Labisch Ditch
Columbia Way Court	EA	1971	175	66	Ditch to Columbia Sl
Cornelius	TF	1959	2,500	950	Tualatin- 84.2
Corvallis	TF	1966	52,440	27,000	Willamette-210.8
Corvallis Airport	L	1962	100	38	Cr to Willamette-222.0
Corvallis Mobile Park	EA	1959	250	49	Oak Cr- 2.6
Cottage Grove	TF	1967	10,000	5,700	Coast Fork Willamette- 35.4
Country Squire Motel	EA-L	1964	650	250	Muddy Cr.- 77.2
Creswell	L	1962	1,750	660	Camas Sw.-8.0
Dallas	AS	1969	15,400	7,600	Rickreall Cr-16.9
Dammasch Hospital	TF	1960	2,500	1,100	Corral Cr.- 1.6

Table 12 (continued). OPERATING MUNICIPAL SEWAGE TREATMENT PLANTS

Plant	Type[a]	year built	Design domestic population equivalent	Design m³/day[b]	Receiving stream river kilometer[a,c]
Dayton	L	1965	1,000	380	Yamhill-8.0
Dike Side Moorage	EA	1973	60	23	Multhomah Ch-19.3
Diamond Hill	L	1966	135	53	Little Muddy Cr.
Dundee	L	1971	1,350	510	Willamette-83.7
Eola Village	TF	1941	1,300	250	S Yamhill-24.1
Estacada	TF	1963	2,500	1,400	Clackamas-38.0
Eugene	TF	1965	106,500	65,000	Willamette-286.4
Eugene Airport	L	1964	150	57	Clear Lake Cr.
Fanno Creek	AS	1969	30,000	11,000	Fanno Cr.-13.4
Fir Cove	P	1957	300	57	Coast Fork Willamette-1.6
Forest Grove	TF-L	1965 1974	30,000	19,000	Tualatin-91.6
Gaston	EA	1964	500	230	Tualatin-103.8
Gervais	L	1965	650	250	Ditch to Pudding-48.3
Goshen School	L	1966	70	26	Wild Hog Cr-1.1
Gresham	AS	1973	30,000	23,000	Columbia R-189.1
Halsey	L	1969	800	360	Muddy Cr.-37.0
Harrisburg	TF	1967	2,000	950	Willamette-259.0
Hayden Island Mobile Home	EA	1972	6,000	2,300	Oregon Sl to Columbia-170.6
Hemlock Subdivision	EA	1966	300	110	M Fork Willamette
Hillsboro-West	AS	1971	20,000	7,600	Tualatin-59.5
Hillsboro-Rock Cr.	AS	1974	30,000	11,000	Rock Cr.-0.8
Hubbard	TF	1968	2,000	760	Mill Cr.-8.5
Illahee Hills	L	1962	500	230	Cr to Willamette-138.4
Independence	L	1967	3,850	1,500	Ash Cr.-2.1
Inverness	EA	1969	20,000	7,600	Columbia-182.6
Jefferson	L	1969	1,080	410	Santiam-11.3
Jubitz Truck Stop	EA	1964	50	19	Columbia Sl
Junction City	L	1967	3,500	4,100	Flat Cr. to Crow Cr.-7.2

Table 12 (continued). OPERATING MUNICIPAL SEWAGE TREATMENT PLANTS

Plant	Type[a]	Year built	Design domestic population equivalent	Design m^3/day[b]	Receiving stream river kilometer[a,c]
King City	EA	1970	2,300	1,000	Tualatin R.
Lafayette	L	1964	1,000	380	Yamhill-12.9
Lafayette Trappist Fndn.	TF	1956	150	42	Cr to Yamhill
Lane Community College	L	1967	1,420	540	Russell Cr.
Laurelwood Academy	TF	1967	400	190	Hill Cr.-9.7
Lebanon	TF	1958	7,500	7,200	S Santiam-28.0
Lowell	TF	1949	3,200	980	Mid Fork Willa-mette-29.8
Lowell Park	EA	1960	120	30	Mid Fork Willa-mette-27.2
Marylhurst	TF	1962	1,100	420	Willamette-35.2
McMinnville	AS	1970	21,600	15,000	S Fork Yamhill-6.4
Metzger	AS	1966	25,000	9,500	Fanno Cr.-7.9
Millersburg School	L	1966	90	34	Crooks Cr.-10.0
Milwaukie	AS	1962	14,000	7,600	Willamette-29.0
Molalla	TF	1955	3,000	1,500	Bear Cr.-0.8
Monmouth	L	1964	7,000	2,600	Ash Cr.- 4.2
Monroe	L	1968	520	200	Long Tom-10.5
Mntn. St. Inv.-Airport Pk	EA-EF	1969	500	190	Columbia Sl
Mt. Angel	TF	1955	2,000	1,400	Pudding-55.8
Newberg	AS	1963	10,000	7,600	Willamette-80.9
Oak Acres Trailer Park	EA	1962	300	110	Subsurface
Oak Hills	EA-L	1965	2,000	760	Willow Cr.-4.3
Oak Lodge San. Dist.	AS	1969 1973	15,000	15,000	Willamette-32.3
Oakridge	AS	1969	4,200	1,600	Mid Fork Willa-mette-64.0
Oregon City	AS	1964	10,000	11,000	Willamette-40.5
Oregon Primate Res. Ctr.	EA-L	1964	600	230	Bronson Cr.-1.6
Panavista Subdivision	EA	1966	100	38	Cr to Cedar Mill Cr
Philomath	AS	1972	3,500	1,300	Mary's R-18.5
Pineway Apartments	EA-L	1964	50	19	S Santiam

Table 12 (continued). OPERATING MUNICIPAL SEWAGE TREATMENT PLANTS

Plant	Type[a]	Year built	Design domestic population equivalent	Design m^3/day[b]	Receiving stream river kilometer
Pioneer Villa	EA	1963	75	30	Courtney Cr.
Pleasant Valley School	EA	1963	130	49	Mitchell Cr.
Portland-Columbia	P	1974	1,100,000	378,000	Columbia-169.7
Portland-Tryon Creek	AS	1965	31,000	19,000	Willamette-32.7
Portland Mobile Home Ct.	TF	1972	620	230	Columbia Sl
Propco	EA	1968	150	57	Columbia Sl
Ramada Inn	EA-L	1965	280	68	Tualatin-12.9
River Bend Mobile Park	EA	1970	500	190	Clackamas-11.3
Riverview Heights	EA	1960	400	190	Dr to Willamette-185.0
Riverview Mobile Ranch	EA	1971	500	190	Clackamas-12.1
River Village Mobile Park	EA	1963	60	30	Willamette-64.4
Royal Highlands	EA	1961	75	30	Small Cr.
St. Helens	P	1959	10,000	11,000	Aerated Lagoon
St. Helens	AL	1971	340,000	110,000	Columbia-138.4
Salem-Willow Lake	TF	1964	73,900	66,000	Willamette-125.8
Salem-West	EA	1969	4,000	1,500	Willamette-128.7
Sandy	AS	1972	5,000	1,900	Trickle Cr.-2.1
Sauvie Island Moorage	EA	1971	75	28	Multnomah Cr-30.6
Scappose	AS-L	1973	5,000	1,900	Multnomah Cr-16.9
Scio	L	1969	600	230	Thomas Cr.-12.9
Sheridan	L	1973	5,250	2,000	S Fork Yamhill-59.5
Sheridan Novitiate	TF	1956	200	57	S Fork Yamhill
Sherwood	TF	1965	1,000	2,200	Cedar Cr.-1.8
Silverton	TF	1969	4,000	2,600	Silver Cr.-5.6
Skyline West S. D.	L	1968	310	91	Oak Cr.
Somerset West	EA-L	1964 1974	1,600	1,200	Beaverton Cr-12.1
Southwood Park S. D.	TF	1962	1,000	380	Ball Cr.- 1.9
Springfield	TF	1962	36,000	26,000	Willamette- 296.5
Stayton	EA-EF	1964 1973	13,500	5,100	N Santiam- 24.1

Table 12 (continued). OPERATING MUNICIPAL SEWAGE TREATMENT PLANTS

Plant	Type[a]	Year built	Design domestic population equivalent	Design m^3/day[b]	Receiving stream river kilometer[a,c]
Stephenson School	EA	1965	60	19	Tryon Cr.
Stuckey's Pecan	L	1969	70	26	Courtney Cr.
Sunset Valley	AS	1965	10,900	5,700	Cedar Mill Cr-4.8
Sweet Home	AS-EF	1974	12,000		S Santiam-54.1
Tangent School	EA	1965	36	30	Cr to Lake Cr.
Tektronix	EA	1963	4,000	980	Beaverton Cr-11.3
Tigard	TF-AS	1970	11,400	5,700	Fanno Cr.-6.0
Timberlakes Job Corps	EA-L	1969	300	190	Clackamas R.
Tualatin	EA-EF	1970	3,500	1,100	Tualatin-13.8
Tualatin Valley Devel. Co.	EA	1965	2,000	760	Tualatin-17.7
Twin Oaks School	TF	1958	120	34	Subsurface Spencer Cr.-7.7
Veneta	L	1971	300	38	Long Tom-48.3
West Hills San. Dist.	EA	1961	300	110	Squaw Cr.
West Linn-Bolton	TF	1963	7,000	4,900	Willamette-38.8
West Linn-Willamette	TF	1963	2,500	1,400	Willamette-45.1
West Tualatin View School	TF	1968	100	38	Subsurface
Willamette Lutheran Homes	L	1962	175	76	Clear Lake
Willamina	L	1966	2,000	760	Willamina Cr-0.8
Willow Island Mobile Est.	EA-L	1973	300	110	Willamette
Wilsonville	EA	1972	5,000	1,900	Willamette-62.8
Woodburn	TF-L	1973	9,560	4,000	Pudding-13.7
Yamhill	EA	1964	750	380	Yamhill Cr.-1.4

[a] Abbreviations:
AL - Aerated Lagoon
AS - Activated Sludge
Cr - Creek
EA - Extended Aeration
EF - Effluent Filtration
L - Lagoon
P - Primary
Sl - Slough
Sw - Swale
TF - Trickling Filter

[b] 1 m^3/day = 264 gpd.

[c] 1 kilometer = 0.622 miles.

Table 13. MUNICIPAL SEWAGE TREATMENT PLANTS WITH MAJOR INDUSTRIAL LOADS[a]

Plant	Design population equivalent		1974 loadings	
	Domestic	Industrial	Domestic	Industrial
Albany	40,700	187,300	21,000	199,000
Corvallis	52,440	95,300	37,900	80,100
Dallas	15,400	20,000	7,000	---
Eugene	106,500	222,000	90,100	404,900
Forest Grove	11,400	129,600	9,670	22,330
Gresham	30,000	10,000	23,800	16,200
Junction City	3,500	4,200	2,600	---
McMinnville	21,600	25,400	12,500	4,900
Mt. Angel	2,000	3,000	2,200	---
Newberg	12,500	3,500	7,000	5,000
Oregon City	10,000	46,000	20,000	5,000
Portland	b	b	385,000	235,000
St. Helens	10,000	330,000	6,000	381,000
Salem	73,900	381,100	100,000	500,000
Sherwood	1,000	4,500	2,850	1,150
Silverton	4,000	16,000	4,550	2,150
Springfield	36,000	4,000	33,000	2,500
Tigard	11,400	1,400	12,200	800
Tualatin	2,455	1,240	2,650	3,600

[a] Data from reference 9 with updates provided by cities and DEQ.
[b] Designed hydraulically for 378,000 m^3/day (100 mgd).

Table 14. SEWAGE TREATMENT PLANTS NO LONGER OPERATING

Plant	Years operational	Design		Type of Plant [b]	Original receiving stream	Flows to now
		m^3/day[a]	PE			
Aloha-Huber	'55-'67	38	500	TF	Beaverton Creek	Aloha
Bailey Hill School	'63-'67	30	300	EA	Ditch	Eugene
Baker Bay	'64-'70	30	1,000	EA	Dorena Reservoir	Ground
Beaver Acres School	'56-'67	38	100	TF	Beaverton Creek	Aloha
Bel-Aire Subdivision	'58-'63	170	450	TF-L	Fanno Creek	Beaverton
BOMARC (Corvallis)	'59-'61	57	150	EA	Willamette	None
Broadmoor	'48-'61	260	1,000	AS	Beaverton Creek	Fanno Creek
Brookford	'55-'61	380	1,000	AS	Fanno Creek	Fanno Creek
Cal Young School	'57-'66	42	580	ST	Willamette	Eugene
Camp Adair	'42-'49	15,100	35,000	P	Willamette	None
Cedar Mill Park	'47-'57	330	1,370	TF	Cedar Mill Creek	Sunset Valley
Columbia Sanitary District	'57-'66	380	1,000	AS	Fanno Creek	Fanno Creek
Country Club Homes	'58-'61	30	80	L	Beaverton Creek	Fanno Creek
Detroit Dam	'48-'53	1,200	3,150	TF	North Santiam	None[c]
Dorena Dam	'47-'53	95	500	ST-ISF	Ground	None[c]
Fannoe Park	'57-'61	30	60	EA	Fanno Creek	Fanno Creek
Furlong	'60-'64	450	1,200	TF	Cedar Mill Creek	Sunset Valley
Grande Ronde Housing	'43-'59	57	300	ST	Rock Creek	Subsurface

Table 14 (continued). SEWAGE TREATMENT PLANTS NO LONGER OPERATING

Plant	Years operational	Design m³/day[a]	Design PE	Type of Plant[b]	Original receiving stream	Flows to now
Green Peter Dam	'64-'74	7.6	20	EA	M Fk S Santiam	Sweet Home[d]
Hillsboro Junior High School	'63-'73	68	900	EA	Beaverton Creek	Hillsboro-Rock
Indian Hills	'63-'65	57	150	EA	Ditch	Portland-Tryon
Jesuit High School	'56-'61	30	500	EA	Beaverton Creek	Fanno Creek
Judson School	'58-'64	57	500	EA	Small Creek	Salem
Lewis & Clark College	'52-'66	450	1,200	P	Willamette	Portland-Tryon
MacLaren School	'53-'72	380	500	TF	Pudding R.	Woodburn
Manbrin Gardens	'47-'68	260	1,000	P	Willamette	Salem
Markham School	'51-'68	38	700	TF	Fanno Creek	Portland-Tryon
McGlassen Village	'62-'65	30	75	EA	Creek to Rock Cr	Aloha
Meadow Lark School	'60-'66	26	280	L	Ditch to Willamette	Eugene
Oak Grove School	'55-'62	76	1,000	TF	Creek to Willamette	Oak Lodge
Orchid	'58-'66	30	100	EA	Fanno Creek	Metzger
Orient Grade School	'54-'73	33	600	TF	Creek to Johnson Creek	Gresham[d]
Peerless Truck	'65-'73	30	75	EA	Tualatin R	Tualatin
Pinebrook Sanitary District	'65-'68	230	580	EA	Fanno Creek	Fanno Creek
Pioneer Trailer Park	'56-'67	30	120	EA	Beaverton Creek	Beaverton
Port of Portland	'41-'74	1,900	3,000	P	Columbia	Inverness
Raleigh Sanitary District	'57-'64	530	1,400	TF	Fanno Creek	Fanno Creek

Table 14 (continued). SEWAGE TREATMENT PLANTS NO LONGER OPERATING

Plant	Years operational	Design		Type of Plant [b]	Original receiving stream	Flows to now
		m^3/day[a]	PE			
Raleighwood Sanitary District	'56-'61	38	100	L	Fanno Creek	Fanno Creek
Rilco Corp.	'61-'72	38	200	TF	Coast Fk Willamette	Cottage Grove
Salemtowne	'67-'73	380	1,000	EA	Winslow Creek	West Salem
Salem						
Wulfer's Trailer	'59-'67	57	250	EA	Little Pudding	Salem
Alumina Plant	e		200		Ground	Salem
Hillcrest	f				Pringle Creek	Salem
State Farm	f				Ditch	Salem
Penet. Annex	f				Mill Creek	Salem
TB Hospital	f				Mill Creek	Salem
Fairview	f				Pringle Creek	Salem
Sugar Plum Sanitary District	'62-'67	57	150	TF	Butternut Creek	Aloha
Sunset Heights	'57-'67	19	500	TF	Beaverton Creek	West Slope SD
Sweet Home Housing	'43-'49	76	350	TF	Creek to Santiam	Sweet Home
Sylvan Heights	'64-'66	30	75	EA	Fanno Creek	Fanno Creek
Tahitian Terrace	'60-'63	34	120	EA	Creek to Fanno C	Fanno Creek
Thunderbird Trailer Park	'62-'72	57	285	EA-L	Creek to Willamette	Wilsonville
Tualatin Hills	'54-'66	450	1,000	TF	Fanno Creek	Metzger
Tualatin Slopes	'52-'55		100	ST	Subsurface	Uplands

Table 14 (continued). SEWAGE TREATMENT PLANTS NO LONGER OPERATING

Plant	Years operational	Design		Type of Plant [b]	Original receiving stream	Flows to now
		m^3/day [a]	PE			
Uplands	'60-'68	570	1,500	TF[g]	Johnson Creek	Sunset Valley
Vermont Hills Sanitary Dist.	'48-'57	38	140	ST-ISF	Fanno Creek	Portland-Columbia
West Hills Convalescent Home	'64-'70	57	150	EA	Fanno Creek	Portland-Columbia
West Tualatin View School	'56-'73	380	1,000	TF	Beaverton Cr.	Subsurface
Westmont	'60-'64	68	175	L	Cedar Mill Cr.	Sunset Valley
Weyerhauser	'49-'64	230	600	P	McKenzie	Springfield
Whitford-McKay	'57-'64	420	1,100	TF	Fanno Creek	Fanno Creek
Wilark Park	'65-'68	130	350	EA	Labisch Creek	Salem
Willamette Manor	'55-'63	530	1,000	P	Willamette	Oak Lodge
Wood Village	'43-'74	760	1,500	TF	Small Creek	Gresham

[a] 1 m^3/day = 264 gpd.

[b] Type of Plant:
- TF - Trickling Filter
- EA - Extended Aeration
- L - Lagoon
- AS - Activated Sludge
- ST - Septic Tank
- P - Primary Treatment
- ISF - Intermittent Sand Filter

[c] Temporary Plant
[d] Via Truck
[e] 1942-1945 to 1951
[f] Before 1939 to 1949
[g] Original Plant: EA (1957)

Table 15. MAJOR OPERATING INDUSTRIAL WASTEWATER TREATMENT PLANTS

Plant and location	Type of process	Receiving stream river kilometer[a]	Allowable Discharges[b], kg/day[c]	
			BOD_5/Suspended Solids	Other[d]
American Can, Halsey	Bleached Kraft pulping and tissue wastes	Willamette - 238.8	1,100/3,200	None
Boise Cascade, St. Helens	Bleached Kraft pulping wastes	St. Helens STP to Columbia - 138.4	Discharge to St. Helens	None
Boise Cascade, Salem	Bleached sulfite pulping and fine paper wastes	Willamette - 135.5	3,600/3,200	None
Crown Zellerbach, Lebanon	Sulfite pulping and linerboard wastes	S. Santiam - 26.5	1,400/1,800	None
Crown Zellerbach, West Linn	Bleached groundwood pulping and fine paper wastes	Willamette - 42.5	1,800/3,600	None
Evans Products, Corvallis	Wet process hardboard wastes; battery separator plant wastes	Willamette - 212.7	900/1,600	None
General Foods - Birds Eye, Woodburn	Fruit and vegetable processing wastes	Pudding - 43.4	110/110	None
Kaiser Gypsum, St. Helens	Groundwood pulp and hardboard wastes	Scappoose Bay - 1.1	410/910	None
Oregon Metallurgical, Albany	Titanium processing wastes	Oak Creek to Willamette - 192.6	0/70	Chlorides - 4,500 Fluorides - 9,000

Table 15 (continued). MAJOR OPERATING INDUSTRIAL WASTEWATER TREATMENT PLANTS

Plant and location	Type of process	Receiving stream river kilometer[a]	Allowable Discharges[b], kg/day[c]	
			BOD_5/Suspended Solids	Other[d]
Pacific Carbide & Alloys, Portland	Calcium carbide electric furnace scrubber wastes and contaminated storm waters	Columbia Slough	0/[e]	None
Pennwalt, Portland	Contaminated cooling water from chlor-alkali process	Willamette - 11.9	0/0	Chlorine - 45 Chromium - 45 Ammonia - 70
Publishers Paper, Newberg	Bleached sulfite, unbleached groundwood pulping, and papermill wastes	Willamette - 80.4	2,700/3,400	None
Publishers Paper, Oregon City	Bleached sulfite and bleached groundwood pulping wastes	Willamette - 44.2	3,600/3,400	None
Rhodia, Portland	Process waste from insecticide production	Willamette - 11.3	0/120	COD[f] - 680 Dissolved solids - 21,000
Stimson Timber, Forest Grove	Groundwood pulping and hardboard wastes	Scoggins Cr - 6.4 to Tualatin - 101.0	No discharge[b]	None
Tektronix, Beaverton	Electroplating wastes	Beaverton Cr - 10.8 to Rock Cr. to Tualatin - 61.9	0/110	Ammonium Ion - 4.5 Fluoride Ion - 3.4

Table 15 (continued). MAJOR OPERATING INDUSTRIAL WASTEWATER TREATMENT PLANTS

Plant and location	Type of process	Receiving stream river kilometer[a]	Allowable Discharges[b], kg/day[c]	
			BOD_5/Suspended Solids	Other[d]
Union Carbide, Portland	Ferro alloys - electro furnace scrubber wastes	Columbia Slough	0/62	Manganese - 5.7 Cyanide - none detectable
Wah Chang, Albany	Process waste from exotic metals production	Truax Cr - 3.2 to Willamette - 185.8	0/320	COD[e] - 450 Dissolved solids- 22,000 Ammonium ion -1,400
Western Kraft, Albany	Unbleached Kraft, neutral sulfite semi-chemical pulping and linerboard wastes	Willamette - 187.4	1,100/2,300	None
Weyerhauser, Springfield	Unbleached Kraft pulping and linerboard wastes	McKenzie - 23.7	1,400/4,500	None

[a] 1 kilometer = 0.622 miles

[b] During low flow period; higher levels during winter.

[c] 1 kg = 2.20 lb.

[d] Inorganic waste streams have many other components.

[e] 50 mg/l suspended solids.

[f] COD - Chemical Oxygen Demand

investigation was limited to the twenty listed firms mainly because of the lack of information regarding expenditures for most other companies. This lack of data is not critical, however, to the objectives of this study. Of all industries having organic wastes--pulp and paper, wood products, food processing--and having their own outfalls, the pulp and paper related firms listed in Table 15 account for about 85 percent of the raw BOD_5 produced and 95 percent of that released to the Willamette River and its tributaries. Also, a check of capital expenditures for industrial pretreatment facilities showed these costs to be extremely low in comparison to the capital costs of the municipal systems to which discharge was made.

Table 16 summarizes pertinent information for existing and authorized federal reservoirs in the Willamette Valley. The existing reservoirs, all operated by the U. S. Army Corps of Engineers, are the ones of concern to this report. Reservoirs belonging to private industry and utilities (e.g., the Eugene Water and Electric Board) have been excluded from this study because they were felt to have a negligible flow augmentation impact when compared to the federal reservoir system. The Scoggins Creek reservoir presently under construction by the Bureau of Reclamation was not considered because this report dealt with the years prior to 1975.

ECONOMIC EXPENDITURES

Figures 14 and 15 represent the capital expenditures made for water pollution control by municipalities during the periods 1914-1945 and 1946-1974, respectively. The expenditures shown are total project costs and no attempt has been made to separate public and private "shares" in those cities where significant amounts of industrial wastes are handled by the municipal system. Municipal cost data was gathered from OSSA and the DEQ annual[45-51] and biennial[52-64] reports, the Environmental Protection Agency's (EPA) Project Register of Construction Grants[65-66], and the results of a Water Resources Research Institute (WRRI) municipal survey.

Figure 16 shows the capital expenditures for in-plant modifications and end-of-the-line treatment facilities made by industry since 1949. The total costs of industrial expenditures which aided water quality and also reduced operational costs (e.g., base conversions and chemical recovery systems at pulping companies) are included in this figure. No allocation of expenditures between these purposes was made. Thus, the industrial expenditures shown may be high. Industrial information came from the OSSA and DEQ reports, a review of DEQ's tax credit files, and a WRRI industrial questionnaire.

Table 16. FEDERAL RESERVOIRS IN THE WILLAMETTE VALLEY

Subbasin reservoir	Stream kilometer[a]	Drainage area km^2[b]	Capacity, $1000m^3$[c] total	Capacity, $1000m^3$[c] usable	Authorized purposes[d]	Type of dam	Year operational	Generating capacity, kW
Tualatin[e]								
Scoggins Cr.[f]	Scoggins Cr. 8.2		75,000	65,000	WQC, FC, I, R, M&I, F&W		1975	None
McKay Cr.[g]	McKay Cr.			23,800				None
Rock Cr.[g]	Rock Cr.			4,700				None
Santiam								
Detroit	N Santiam 79.3	1130	561,000	419,000	FC, N, I, P	Concrete	1953	100,000
Big Cliff	N Santiam 74.7	1170	7,310	2,960	P, RR	Concrete	1953	18,000
Foster	S Santiam 60.7	1280	75,000	41,400	FC, P, RR	Rock Fill	1966	20,000
Green Peter	M Santiam 9.2	717	530,000	411,000	FC, N, I, P	Concrete	1966	80,000
Cascadia[g]	S Santiam 77.2			179,000	FC, N, I			None
Calapooia								
Holley[g]	Calapooia 73.2			110,000	FC, N, I			None
McKenzie								
Cougar	S Fk McKenzie 7.2	539	271,000	204,000	FC, N, I, P	Rock Fill	1963	25,000
Strube[g]	S Fk McKenzie 4.0			3,700	P, RR			39,500
Blue River[h]	Blue R. 2.7	230	110,000	104,000	FC, N, I	Rock/Gravel	1968	None
Gate Cr.[g]	Gate Cr. 0.6			62,000	FC, N, I			None
Long Tom								
Fern Ridge	Long Tom 41.4	707	124,800	136,000	FC, N, I	Earth	1941	None
Mid Fork								
Look Out Point	M Fk Willam. 32.0	2570	562,000	431,000	FC, N, I, P	Earth/Concrete	1954	120,000
Dexter	M Fk Willam. 27.0	2590	30,000	5,900	P, RR	Earth/Concrete	1954	15,000
Hills Creek	M Fk Willam. 72.2	1010	439,000	307,000	FC, N, I, P	Earth/Gravel	1961	30,000
Fall Creek	Fall Cr. 11.6	477	154,000	142,000	FC, N, I	Rock Fill	1965	None
Coast Fork								
Cottage Grove	C Fk Willam. 47.8	269	41,000	37,100	FC, N, I	Earth/Gravel	1942	None
Dorena	Row R. 12.2	686	95,600	87,000	FC, N, I	Earth	1949	None

[a] 1 Kilometer = 0.622 mile.
[b] 1 km^2 = 0.386 $miles^2$.
[c] $1,000m^3$ = 0.811 acre feet.
[d] FC-Flood Control; N-Navigation; I-Irrigation; P-Power; R-Recreation; M&I-Municipal and Industrial F&W-Fish and Wildlife; WQC-Water Quality Control; RR-Reregulating.
[e] Tualatin Reservoirs: Bureau of Reclamation; all others: Corps of Engineers.
[f] Under construction.
[g] Authorized.
[h] Two dams involved: a main dam and an auxiliary dam.

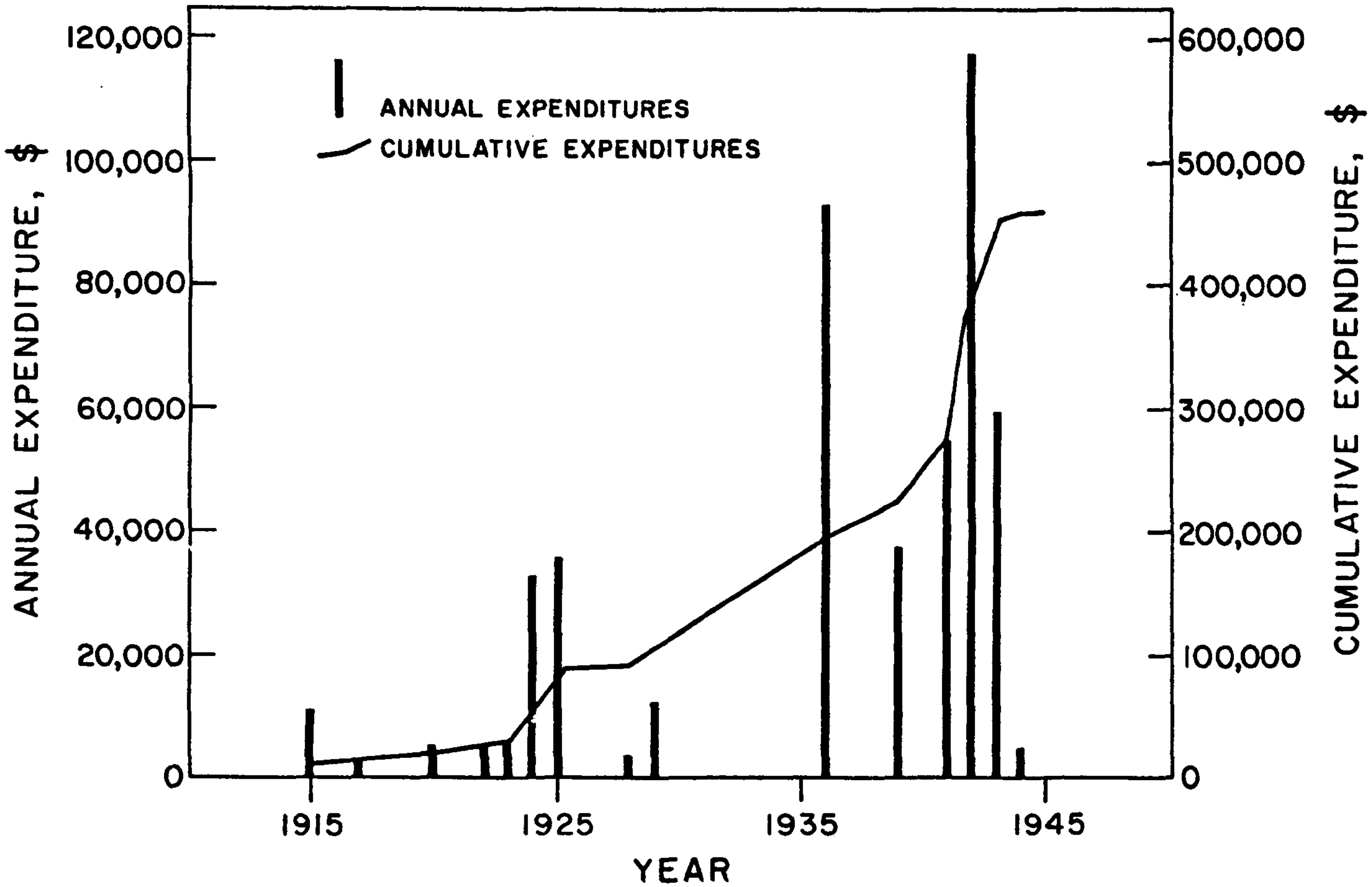

Figure 14. Capital expenditures for municipal sewage collection and treatment: 1915-1945.

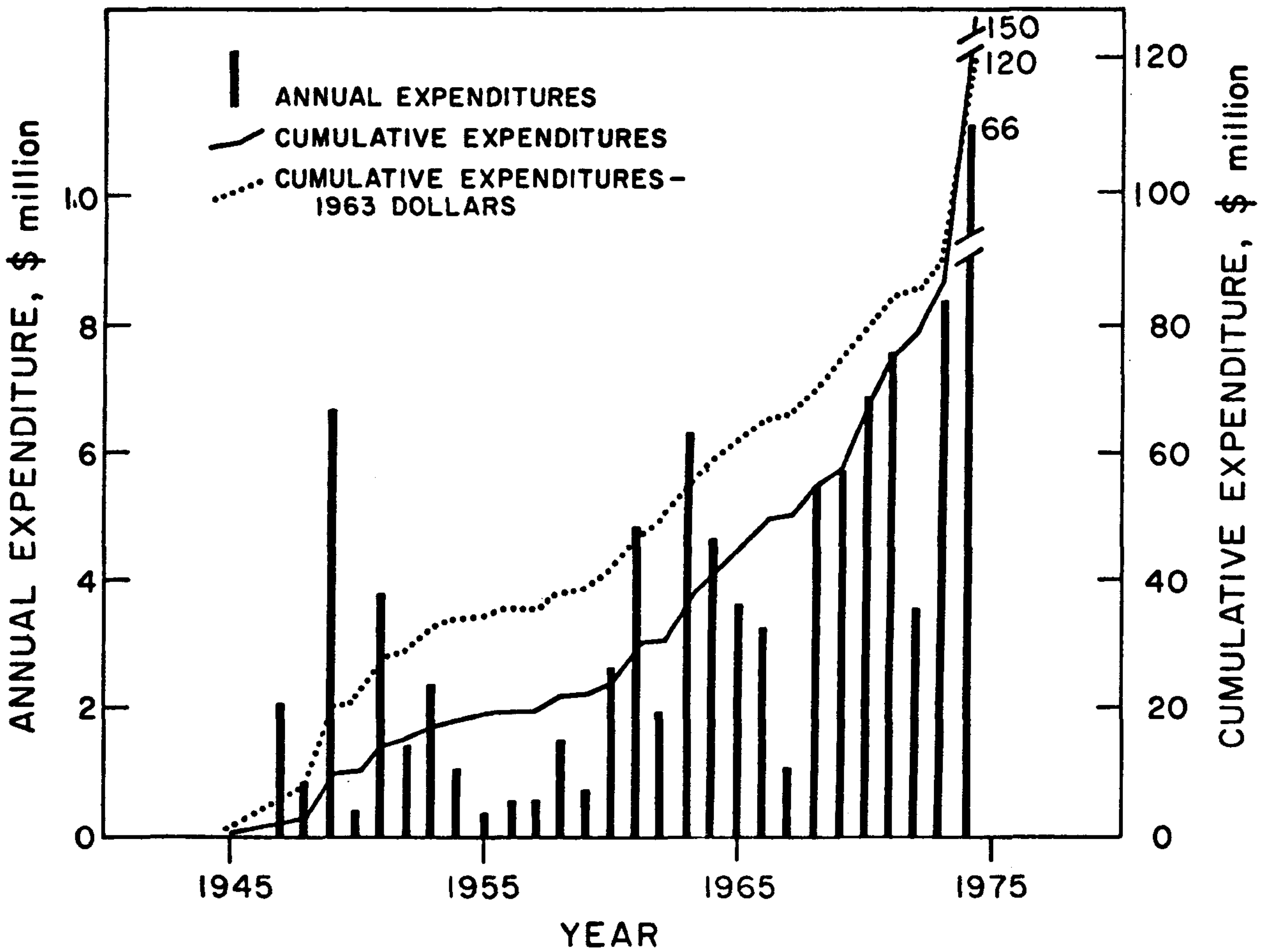

Figure 15. Capital expenditures for municipal sewage collection and treatment: 1946-1974.

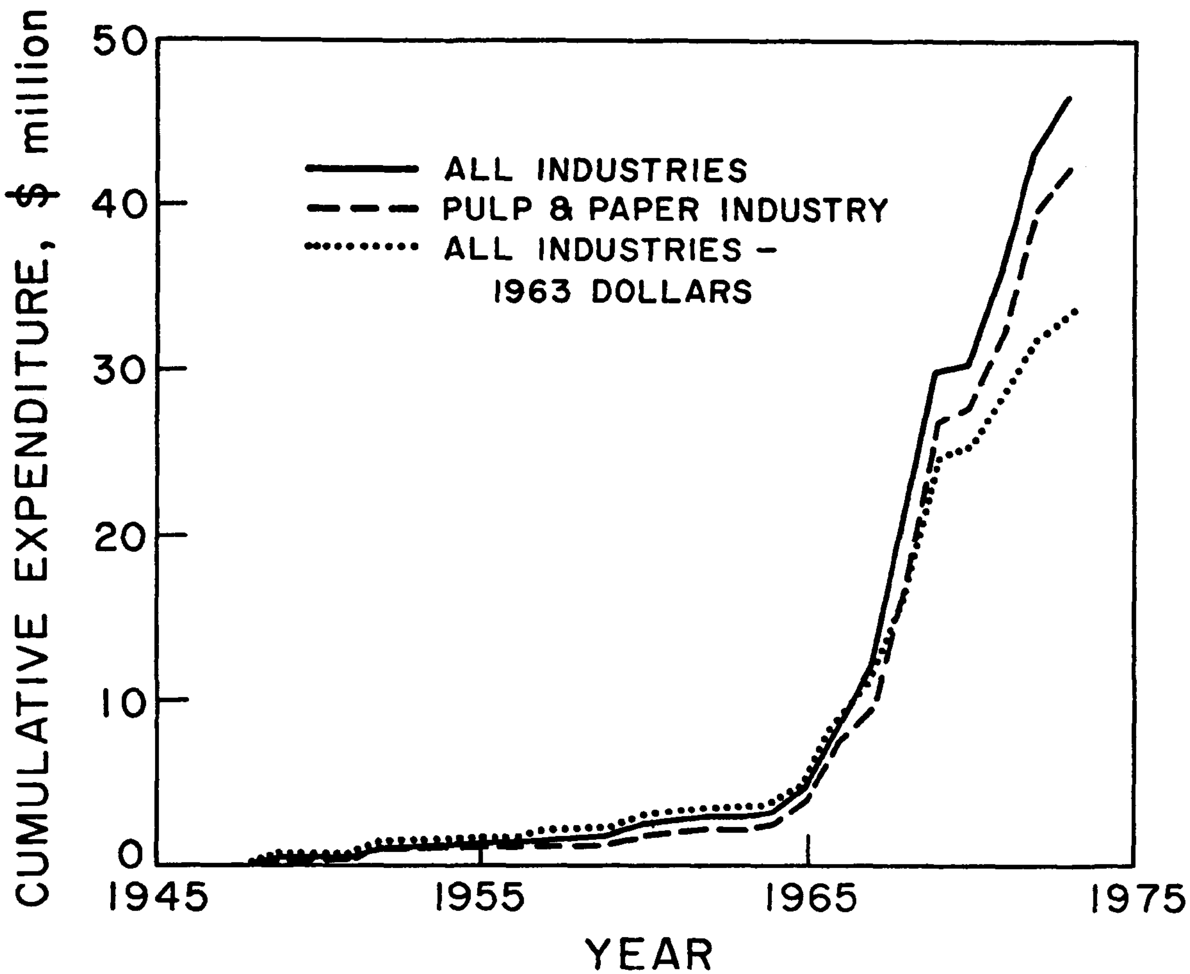

Figure 16. Capital expenditures for the control of industrial wastewaters: 1949-1974 (by the firms listed in Table 8).

Table 17 is a compilation of capital cost and financing information relating to the existing federal reservoirs. To date, slightly more than 400 million dollars have been spent for their construction. In terms of 1963 dollars the figure is about 520 million. But what portion of this can be "allocated" to water quality control? The Definite Project Reports or General Design Memoranda for nine of the thirteen reservoirs included annual water quality control (WQC) benefits as part of the benefit-cost analyses (see Table 17).[67-79] The WQC benefit allowed ranged from 1.2 to 5.5 percent of the total benefits. Assuming an average value of 3.0 percent, the WQC portion of the capital cost is about 12 million dollars (15 million 1963-dollars).

Such a cost allocation can be justified only on the basis of the limited time and resources available to address this issue. Any system to allocate costs which are "joint" in the economic sense is arbitrary to some degree. However, an allocation system sensitive to the real water quality benefits generated by the reservoirs would have been more defensible. It is likely that the method employed in this study only sets a lower bound on water quality improvement costs.

ENERGETIC EXPENDITURES

Methodology

The documentation of energy expenditures involved in constructing the facilities listed in Tables 12 through 16 presented problems in that there existed no clearcut, standard methods of evaluating such costs.

A direct approach is a difficult one. It depends upon breaking up the construction of each facility into a number of components (e.g., earthwork, reinforced concrete, equipment), following as closely as possible the engineer's estimates of direct costs. The same steps would then be taken again for each component to evaluate the energies required to manufacture the various materials, shape them into specific products, transport them, and incorporate them into the component.

This approach could be directed to some very specific projects and hence has the advantage of realism. It is obvious, of course, that with about 200 municipal treatment systems, the 20 chosen industrial systems, and the 13 Corps of Engineer reservoirs constructed over a 30-year period, the task of handling the large amount of detailed information is a formidable one. Nor is all the necessary information readily available. The breakdown of the construction elements is possible only for large, aggregated classes. Direct and indirect energy requirements for these components are difficult to ascertain. An alternative approach had to be found.

Table 17. FINANCING INFORMATION FOR EXISTING FEDERAL RESERVOIRS, WILLAMETTE BASIN.

Subbasin reservoir	Estimated costs, charges, and benefits[a]							Total construction cost[d], 10⁶ dollars	Annual O & M cost[e], 10⁶ dollars
	Base year	Amortization period, years	Interest rate, %	Total cost[b], 10^6 dollars	Annual charges[c], 10^6 dollars	Annual benefits, 10^6 dollars	Annual water quality benefits, 10^6 dollars		
SANTIAM									
DETROIT	1951	50	3	62.2	2.67	3.82[f]	0.044[f]	63.1[f]	0.587[f]
BIG CLIFF	1951	50	3	9.2	0.45				
FOSTER	1962	100	2 1/2	29.6[g]	0.98	6.38[g]	0.152[g]	26.0	
GREEN PETER	1959	50	2 1/2	68.2[g]	3.27[g]	4.13[g]	0.129[g]	57.0	0.615[f]
McKENZIE									
COUGAR	1956	50	2 1/2	41.5	1.86	2.91	0.070	54.3	0.211
BLUE RIVER	1963	100	2 5/8	33.6	1.02	2.38	0.028	28.9	0.052
LONG TOM									
FERN RIDGE	1939			2.6				6.0	0.166
MID FORK									
LOOKOUT POINT	1940	50	3	34.8	1.48	1.62	0.041	87.9[f]	0.673[f]
DEXTER	1951	50	3	13.1	0.65				
HILLS CREEK	1955	50	2 1/2	34.8	1.47	2.93	0.120	45.7	0.164
FALL CREEK	1961	50	2 5/8	28.8	1.12	2.38	0.131	21.1	0.091
COAST FORK									
COTTAGE GROVE	1939			2.3				2.7	0.162
DORENA	1940			4.4				14.1	0.136

[a] Data from appropriate Definite Project Reports or General Design Memoranda written prior to construction.

[b] Total investment, including recreation facilities.

[c] Includes interest, amortization, operation and maintenance, replacements, and taxes foregone.

[d] Source: "Water Resources Development by the Army Corps of Engineers in Oregon", 1973.[80] Excludes recreation facilities.

[e] Source: "Extract: Report on the Improvements in the Portland, Oregon, District", Fiscal Year 1972.[81]

[f] Combined benefits and costs of principal and reregulating dam.

[g] Includes the then planned White Bridge Reregulating Reservoir with estimated cost of $11.3 million.

Fortunately, economic analysis provides an analog which is useful in this context. Specifically, input-output (I-O) analysis is applied in this study to estimate total (direct and indirect) energy requirements. Before addressing the subject of estimating energy requirements through the input-output technique, a brief description of the nature and use of this technique in economics is necessary.

The study of the interdependency of the economics system has long been an important aspect of economic studies; but during the 1930's this study focused for the first time on the empirical relationships underlying the structure of the American economy.[82] This structure was studied by dividing the economy into a number of relatively homogeneous industrial sectors and observing the flows of goods and services among them. It is, perhaps, easiest to describe this framework by use of a simple example.

Assume a simple economy with four sectors: Agriculture (I), Manufacturing (II), Construction (III), and Energy (IV). The fundamental input-output relationships are presented below.

	I	II	III	IV	Final Demand (y_i)	Total Output (X_i)
I	x_{11}	x_{12}	x_{13}	x_{14}	y_1	X_1
II	x_{21}	x_{22}	x_{23}	x_{24}	y_2	X_2
III	x_{31}	x_{32}	x_{33}	x_{34}	y_3	X_3
IV	x_{41}	x_{42}	x_{43}	x_{44}	y_4	X_4

The crucial elements in this table are the X_{ij}'s on the left side. They represent the dollar value of the flow of goods and services from the sector listed on the left of a particular cell to that listed as the column heading. Thus x_{12} represents the value of goods and services flowing from the agricultural to the manufacturing sector. These elements are referred to as "interindustry demands" because they reflect the requirements which one sector places on the production of other sectors in order to meet its own production goals.

The elements y_i are "final demands". They reflect largely household consumption, exports, investments, and government purchases. Interindustry demands plus final demands must equal a sector's total output (X). Thus, the following equation can be written for sector I, for example:

$$x_{11} + x_{12} + x_{13} + x_{14} + y_1 = X_1$$

Or, in general terms, the equation is:

$$\Sigma\, x_{ij} + y_i = X_i \qquad (1)$$

There are two ways of obtaining the numerical estimates of the x_{ij}'s. First, one can observe the transactions in dollar terms of the goods and services flowing from one sector to another to determine the inter-industry demands. Secondly, one can make use of the assumption that input requirements of a sector are directly proportional to that sector's output. These input requirements are technologically fixed and can be derived from knowledge of technical production relationships. Equation (2) can be written as:

$$x_{ij} = a_{ij} X_j \tag{2}$$

The terms of our example, x_{12} (the value of goods and services flowing from the agricultural to the manufacturing sector) is a function of the level of output of the manufacturing sector (X_2) and the technical coefficient, a_{12}.

It should be noted here that I-O analysis uses linear approximations to describe economic interactions. Thus large changes in one or more sectors could significantly alter the coefficients employed. Other shortcomings of using the input-output technique in this application are those generally attributable to the use of this mode of analysis. These are discussed elsewhere and are well-known.[83] They are not especially limiting in this application. The reader is cautioned, however, that the fixity in technology assumption, which this analysis employs, would become especially troublesome when predictions about energy use are made in a situation when energy price relationships are expected to change. In contrast, energy prices were relatively stable during the period of this analysis.

Equation (2) can be substituted into equation (1) to obtain:

$$\Sigma\, a_{ij} X_j + y_i = X_i \tag{3}$$

Returning briefly to the subject of the interdependent nature of the economic system, it is apparent from the transactions table and from equation (1) that a change in output of any sector will cause the output of other sectors to change. This is because the interindustry demands faced by these sectors will be altered. These output changes will again cause outputs to respond in other sectors. What will be the extent of these output changes? Solving equation (3) for output provides the answer.

In matrix notation equation (3) is written as

$$AX + Y = X$$

where, for this example,

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \quad X = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} \quad Y = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix}$$

$$X - AX = Y \text{ and}$$
$$X = (I-A)^{-1} Y \tag{4}$$

where I is an identity matrix.

Designating the elements of $(I-A)^{-1}$ as c_{ij}, the matrix for this example can be written as:

$$(I - A)^{-1} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix}$$

In this example, the interpretation of the c_{ij}'s is very important. Where a_{12} yielded the direct output requirement from sector I as the output of sector II changed by one unit, c_{12} yields the total (direct and indirect) output requirement from sector I as the output from sector II changes by one unit. The latter accounts for all interindustry relationships in the economy.

This brings us almost to the solution of the problem. Postulating that, because of increased water quality requirements in the Willamette River System, the output of the construction sector (III) increases by one dollar, then the coefficient c_{43} will yield the estimate of the output response required from the energy sector (IV).

Only one problem remains. The predicted output response of sector IV is in value terms (dollars); the interest here is in predicting the response in terms of physical units (Joules). It would be a simple matter of dividing the value estimate by the price of energy to obtain the response in physical units. It is known, however, that energy is sold to various sectors at different prices. (This point and the prices actually used in the calculations are taken from Herendeen.[84]) To estimate the number of physical units of energy required to serve a change in the final demand of the construction sector, Δy_3, a more complicated procedure must be employed.

Equation (4) allows us to write

$$\Delta X = (I - A)^{-1} \Delta Y \quad . \tag{5}$$

Equation (5) can be written as

$$\begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix} \begin{bmatrix} \Delta y_1 \\ \Delta y_2 \\ \Delta y_3 \\ \Delta y_4 \end{bmatrix} = \begin{bmatrix} \Delta X_1 \\ \Delta X_2 \\ \Delta X_3 \\ \Delta X_4 \end{bmatrix} \tag{6}$$

As we assumed the final demand to change in the construction sector only, $\Delta y_1 = \Delta y_2 = \Delta y_4 = 0$. According to equation (6) output changes in the economy then become

$$\begin{aligned} \Delta X_1 &= c_{13}\Delta y_3 \\ \Delta X_2 &= c_{23}\Delta y_3 \\ \Delta X_3 &= c_{33}\Delta y_3 \\ \Delta X_4 &= c_{43}\Delta y_3 \end{aligned}$$

These ΔX_i's represent the total value of output change associated with Δy_3 (a change in the final demand of the construction sector).

Of primary interest is the output change of the energy producing sector (ΔX_4). ΔX_4 represents the change in the value of output of the energy producing sector. Assuming that prices vary according to the sector to which Sector IV sells its output, then it becomes necessary to know how ΔX_4 is composed. In other words, the changes in the values of output flowing from sector IV to each of the sectors of the economy must be known. To estimate these flows equation (2) is utilized to write:

$$\Delta x_{ij} = a_{ij}\ \Delta X_j \tag{7}$$

The right side of equation (7) is the matrix:

$$\begin{bmatrix} a_{11}\ \Delta X_1 & a_{12}\ \Delta X_2 & a_{13}\ \Delta X_3 & a_{14}\ \Delta X_4 \\ a_{21}\ \Delta X_1 & a_{22}\ \Delta X_2 & a_{23}\ \Delta X_3 & a_{24}\ \Delta X_4 \\ a_{31}\ \Delta X_1 & a_{32}\ \Delta X_2 & a_{33}\ \Delta X_3 & a_{34}\ \Delta X_4 \\ a_{41}\ \Delta X_1 & a_{42}\ \Delta X_2 & a_{43}\ \Delta X_3 & a_{44}\ \Delta X_4 \end{bmatrix}$$

The technical coefficients and the ΔX_j in the above matrix are known. Its bottom row represents the dollar values of deliveries from the energy sector to each of the other sectors of the economy to satisfy the change in final demand faced by the construction sector (ΔY_3). If P_{41}, P_{42}, P_{43}, and P_{44} are the prices at which energy is sold to sectors I, II, III, and IV, respectively, then the total output change in physical units required from the energy sector (ΔE_4) to meet the change in final demand of the construction sector (ΔY_3) can be obtained using equation (8):

$$\Delta E_4 = \frac{a_{41}\ \Delta X_1}{P_{41}} + \frac{a_{42}\ \Delta X_2}{P_{42}} + \frac{a_{43}\ \Delta X_3}{P_{43}} + \frac{a_{44}\ \Delta X_4}{P_{44}} \quad (8)$$

The I-O model employed broke the economy up into 362 sectors, five of which were energy suppliers (coal, crude oil and gas, refined petroleum, electricity, and natural gas).[84]

The use of the I-O energy model allowed the researchers to calculate the "direct" energy requirement per dollar of sales in a particular sector and the "indirect" energy needs of all the other sectors combined required to support a dollar of sales in the first industry. Figure 17 will help clarify the differences between "direct" and "indirect" requirements.

As can be seen from the figure, "direct" energy sales included only those made directly by the five energy sectors to another sector (construction in this case). "Indirect" energy sales were those made by the five energy sectors to any other for its support of the industry in question. It should be noted that the "indirect" energies included only operational energies and excluded capital energies. Referring to Figure 17, this means the energy required to build the steel mill is excluded; only the energy required to make the steel is included. It is felt that negligible error results from this practice.[85]

A problem involved with using this method is the exclusion of energy costs of imports to the economy, which introduced about a ten percent error. The entire procedure yielded answers that were felt to be within fifty percent of the actual value.[85]

Results

The I-O-energy model approach to converting dollar costs of construction to energy costs was employed on the expenditures discussed earlier in this chapter. Table 18 lists the values of the coefficients used in the conversion process. The coefficients are energy conversions for the particular category of construction which includes dams and sewerage works.

Table 19 presents the results of applying the coefficients to the construction costs of the facilities previously discussed.

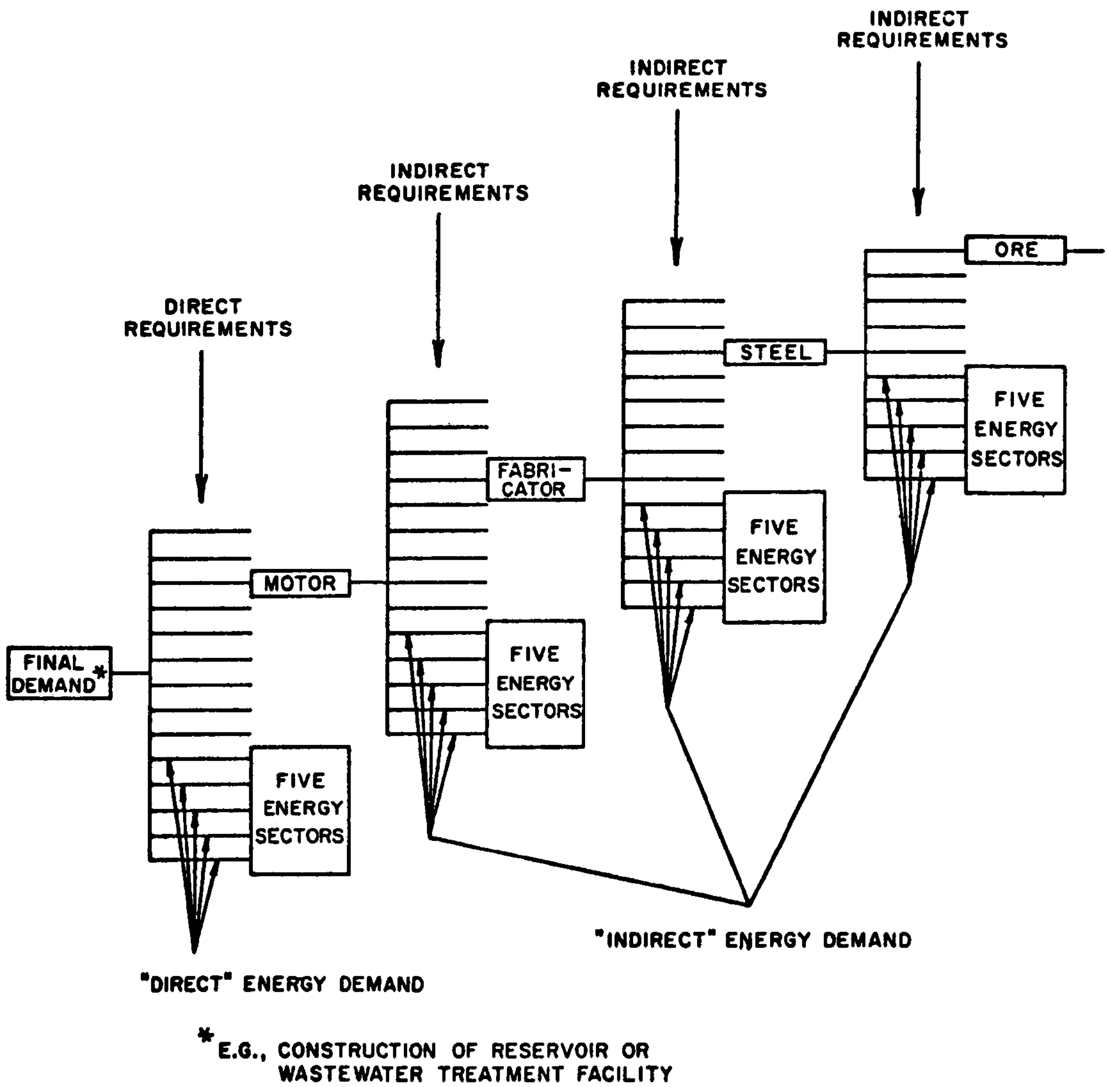

Figure 17. Input-output-energy model energy flows.

Table 18. COEFFICIENTS USED IN CONVERTING CONSTRUCTION DOLLARS TO ENERGY VALUES[a]

Energy	Coefficients, Mega Joules (MJ)/dollar[b]	
Type	Direct	Total
Coal	0.000	25.996
Crude oil and gas	0.000	47.008
Refined petroleum	8.560	26.644
Electricity	0.211	3.631
Natural gas	0.410	21.258
Total	9.181	124.537

[a] Source: reference 84, construction sector 11.05; based on 1963 dollars.

[b] 1 MJ = 948 British Thermal Units (BTU).

Table 19. ENERGY COSTS OF CONSTRUCTING THE WATER POLLUTION CONTROL FACILITIES OF THE WILLAMETTE BASIN

Facility classification[a]	Construction costs, 1963 dollars	Direct energy requirement, Tera Joules (TJ)[b]	Total energy requirement, TJ[b]
Municipal facilities			
Treatment plants	74,000,000	680	9,200
Interceptors	41,000,000	380	5,100
All facilities	120,000,000	1,100	15,000
Industrial facilities	34,000,000	310	4,200
Reservoirs			
Total	520,000,000	4,800	65,000
3% - WQC[c]	15,000,000	140	1,900

[a] As defined; see text for full description of facility classification.

[b] 1 TJ = 948×10^6 BTU.

[c] 3% allocated for water quality control.

Verification

A verification of the results of applying the I-O-energy model concept to the construction of the water pollution control facilities was carried out and the procedure is outlined here. The direct construction energy requirements for one recently completed activated sludge wastewater treatment plant and for two reservoirs, Green Peter Lake, having a concrete dam and power production facilities, and Blue River Lake, having two earth filled dams and no power producing facilities, were investigated in detail. The results of the earthwork energy (i.e., energy per unit of excavation and backfill) calculations for the activated sludge plant were then applied to ten other treatment facility construction projects in an effort to expand the verification.

The appropriate findings of the report "Energy Use in the Contract Construction Industry"[86] were also used as a means of checking the direct construction energy requirements estimated by the I-O-energy methodology. The results of this report are based upon estimated energy requirements in different construction categories (e.g., heavy construction, sewerage works) as a function of a project's monetary value. The report also allows the user to estimate the energy needs for various items (e.g., earthwork) within each category. It should be noted that this report is not for contract estimating purposes but rather for evaluating the effects of various energy supply situations on different construction sectors.

Table 20 presents comparisons of the I-O-energy methodology results, the values arrived at using the report[86] mentioned above, and the estimates made by the researchers for the three projects investigated in detail. Also included in Table 20 is the energy required to manufacture just the cement and the reinforcing steel that went into the projects.

Table 21 is a comparison of direct construction energies of 10 treatment plants utilizing the three methods discussed above. Also included is the energy required to manufacture the cement and reinforcing steel that went into the facilities.

Several important notes should be made regarding the comparisons which Tables 20 and 21 present. One, the energy need estimated using the I-O-energy model approach is consistently lower than the requirement estimated using the construction energy study.[86] This may be true for several reasons including: 1) the report is based upon 1973 costs while the I-O-energy methodology is founded upon a 1963 transactions table of the economy--construction has, in general, become more energy intensive with time; 2) the energy pricing portion of the I-O-energy method work, based upon national data, may have priced energy supplied to the construction sector too high for use in the Willamette Basin--

Table 20. COMPARISON OF DIRECT CONSTRUCTION ENERGY REQUIREMENTS OF THREE PROJECTS

Project Energy type	Direct energy requirement, TJ[a] Via I-O-energy methodology	Via reference 86 Total	Via reference 86 Appropriate items[b]	Via direct calculation[c]	Materials[d] energy, TJ[a]
Green Peter Lake					
Refined petroleum	488	779	430	236	
Electricity	12	41	0	71	
Natural gas	23	0	0	0	
Total	523	820	430	307	780
Blue River Lake					
Refined petroleum	247	534	290	396	
Electricity	6	28	0	1	
Natural gas	12	0	0	0	
Total	265	562	290	397	90
Activated sludge plant					
Refined petroleum	15	35	12	7.3	
Electricity	0.3	2	0	0	
Natural gas	0.7	0	0	0	
Total	16	37	12	7.3	35

[a] 1 TJ = 948 x 10^6 BTU.

[b] Appropriate items selected to facilitate comparison with direct calculation: earthwork and concreting for Green Peter and Blue River Lakes; earthwork only for activated sludge plant.

[c] For earthwork and concreting at Green Peter and Blue River Lakes; earthwork only for activated sludge plant.

[d] Energy required to manufacture just cement and reinforcing steel included in project.

Table 21. COMPARISON OF DIRECT CONSTRUCTION ENERGY REQUIREMENTS OF WASTEWATER TREATMENT PLANTS

Plant	Direct energy requirement, TJ[a]				Materials[b] energy, TJ[a]
	Via I-O-energy methodology	Via reference 86		Earthwork via direct calculation	
		Total	Earthwork		
1	5.1	12	3.7	0.36	5.7
2	14.0	29	9.1	1.1	27.
3	4.5	11	3.3	0.09	5.3
4	7.2	17	5.2	0.19	6.5
5	11.0	24	7.4	0.36	12.
6	8.6	13	4.1	0.13	5.5
7	10.0	23	7.1	0.83	16.
8	7.7	17	5.4	0.45	14.
9	25.0	52	16.	0.93	c
10	5.0	12	3.7	0.29	5.5

[a] 1 TJ = 948 x 10^6 BTU.

[b] Energy required to manufacture just cement and reinforcing steel included in project.

[c] Not available.

thus the energy/dollar conversion coefficient might be low; and 3) the construction energy report[86] is based upon estimating energy needs in construction--it is possible that overestimating may have occurred.

Two, note how the direct calculations compare with the values of the first two methods. For the two reservoirs in Table 20 the major energy uses--excavation and concrete work--were considered. For the activated sludge plant, all the major earthwork items were considered, but concreting was excluded. The direct calculations for these three jobs show fairly good correlation with the other methods. For the 10 treatment plants in Table 21, however, it can be seen that the directly calculated earthwork energy values are quite low compared with the values of the other methods. This is because only the excavation and backfill earthwork items were checked. (The inclusion of energy required to make concrete, i.e., transport of aggregate from borrow to batch plant, batch plant operation, and ready-mix transport, would not significantly increase the reported values.) This poor verification may have occurred for several reasons including: 1) general excavation and backfill require quite low energy inputs per unit of work compared to other earthwork items (e.g., riprap work, offsite disposal of materials); 2) an energy requirement per unit of estimated excavation and backfill was applied only once, while it is not uncommon to move the same earth several times (e.g., opening up a trench more than once to put in various utilities); and 3) efficiencies may have been much lower than that assumed in the calculation, i.e., idling equipment may utilize much more fuel than reckoned.

Finally, note the large amount of energy required to produce just the cement and reinforcing steel that goes into the facilities in Tables 20 and 21. Considering the many products and pieces of process equipment that make up these water pollution control facilities, it is not difficult to see why the total energy coefficients of Table 18 are so much larger than the direct coefficients.

Direct energy requirements for interceptor construction were not investigated, but a relatively high portion of contract amounts in this type of building would be for earthwork. Thus, direct energy requirements would be relatively high.

SECTION VIII

OPERATION AND MAINTENANCE EXPENDITURES

MUNICIPAL SYSTEMS

O & M costs of municipal wastewater treatment systems as well as those of private sewage systems for the period 1973-74 were investigated. Municipal data was gathered from a survey of monthly reports submitted to the DEQ by plant operators, a review of recent EPA O & M audits, and the results of a WRRI treatment plant survey. Most of the information gained is tabulated in the Appendix.

To arrive at the total annual dollar and energy expenditures required to operate and maintain municipal treatment works in the Willamette Valley, considerable estimating was required. Different methods of estimating were used in various areas and the appropriate discussions are to be found in the sections below. Regression analyses were carried out where statistical significance existed.

O & M costs were researched for the interceptor portion of municipal collection systems. Operational costs are mainly restricted to those of running pump stations and depend significantly upon topography and flow variation. Maintenance costs for cleaning, inspection, and normal repair are low; most collection system maintenance needs are for the smaller sewers "upstream" of the interceptors. More detail is given in subsequent paragraphs.

Treatment Facilities

Electrical Requirements --- Large amounts of electrical energy are used in the treatment of sewage, mainly for pumping and aeration, where employed. Information relating to periodic electrical usage was gathered. In those instances where a periodic dollar expenditure was known but an energy consumption figure was lacking, the "National Electric Rate Book"[87] was employed to estimate the missing figure.

Figure 18 is a plot of unit cost as a function of daily usage. Figure 19 relates consumption to average flow; the variation on energy intensiveness for differing processes is very noticeable. Figures 20 and 21 present electrical unit requirements as a function of total pollutant removal per day for 5-day Biochemical Oxygen Demand (BOD_5) and suspended solids, respectively. The variation between processes is also noticeable here.

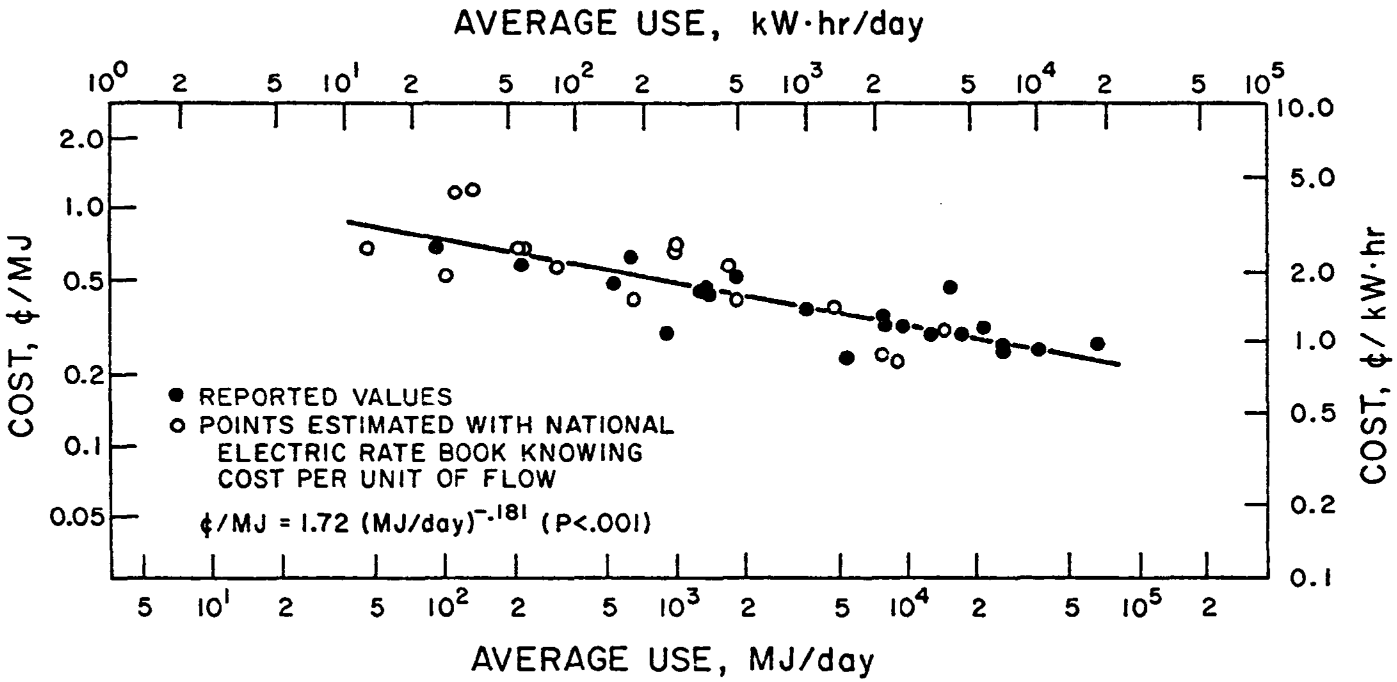

Figure 18. Electrical unit cost vs. daily consumption.

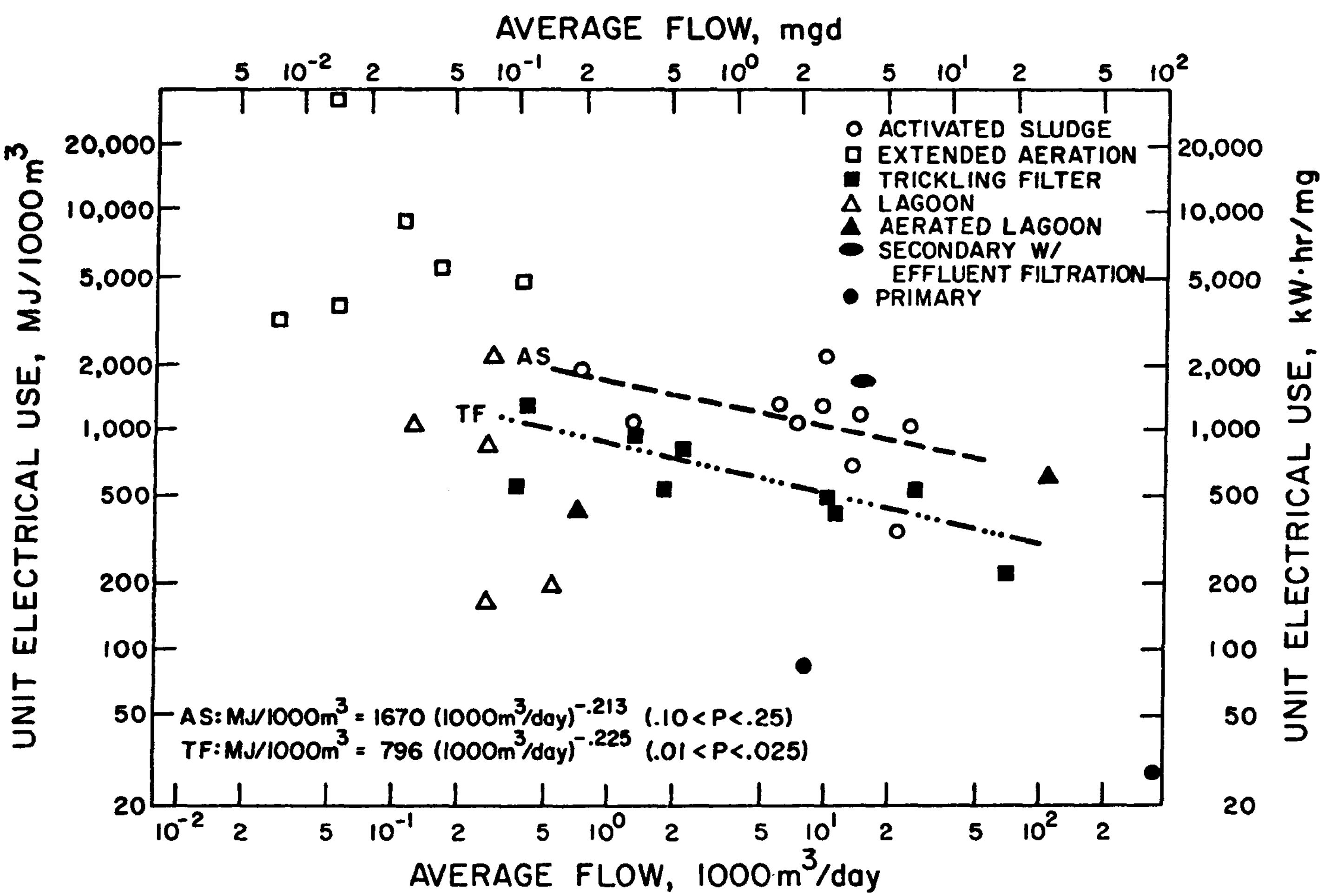

Figure 19. Electrical use vs. wastewater flow.

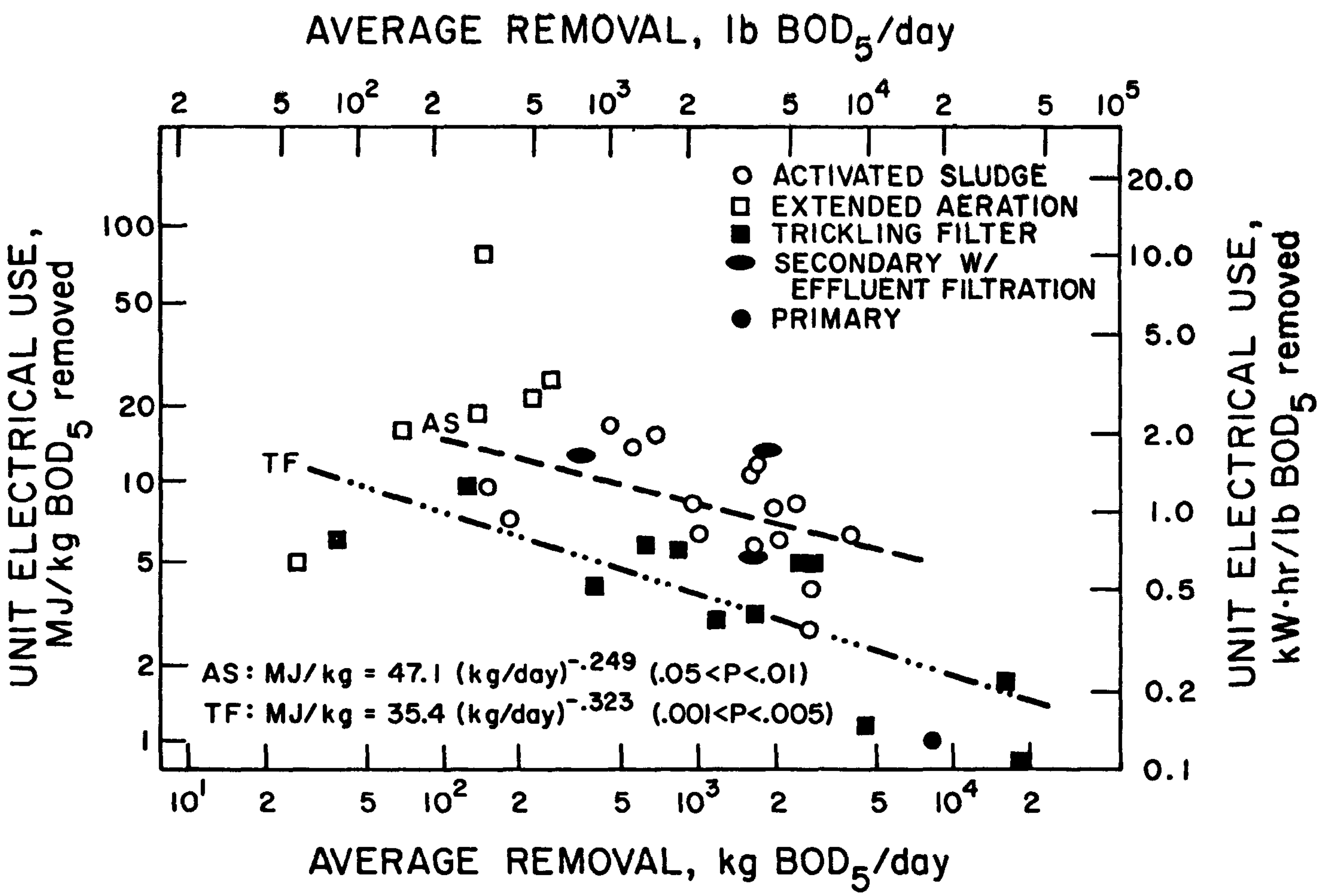

Figure 20. Electrical use vs. BOD_5 removal.

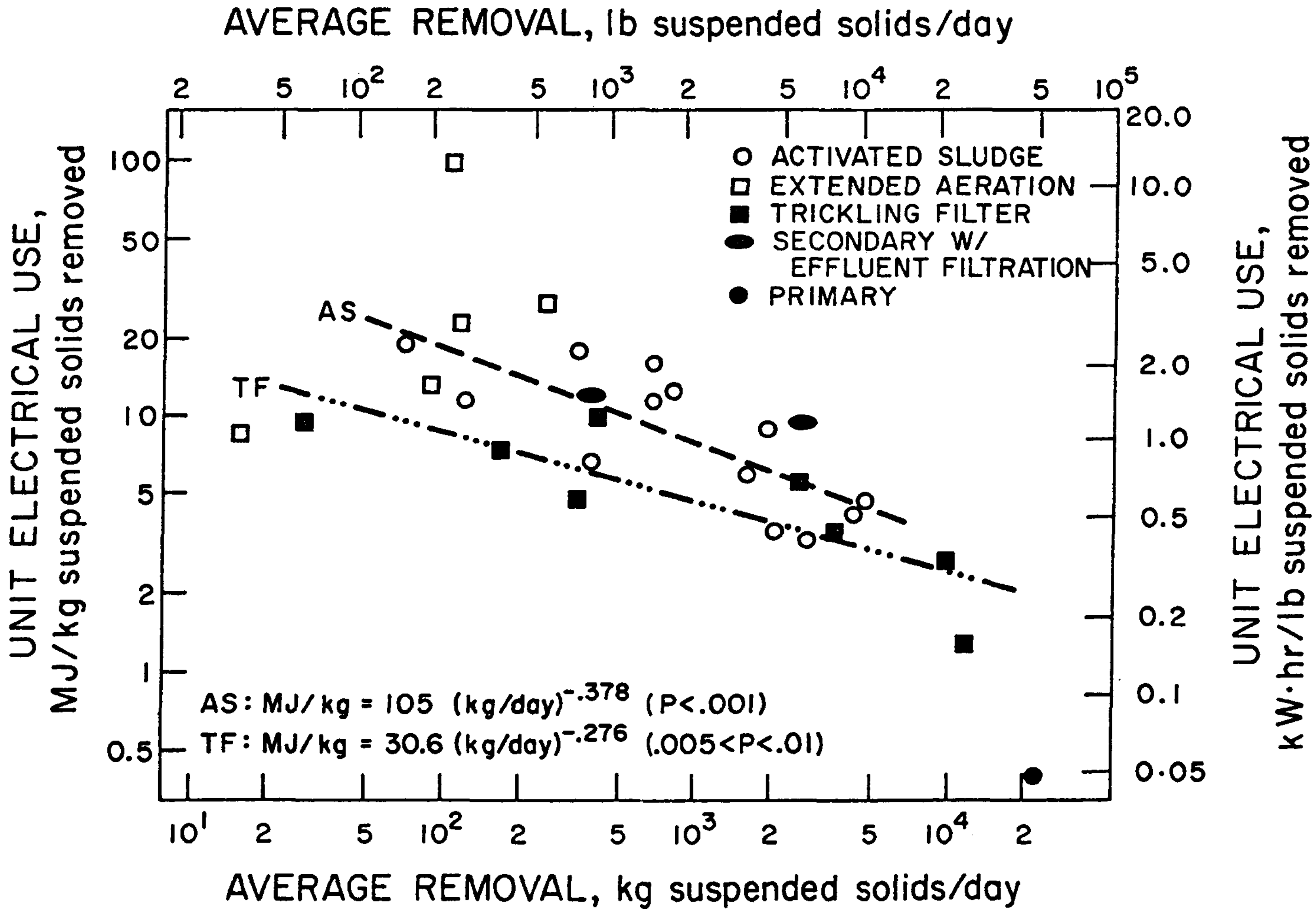

Figure 21. Electrical use vs. suspended solids removal.

The work of Smith[88] was utilized to check the results. His calculations range from 10 to 40 percent below the values presented in Figure 19. Smith's work is based upon summing the calculated electrical requirements for the motors which operate the various pieces of plant equipment, where as Figure 19 presents total requirements without looking at individual machinery. The different methodologies may, in part, explain the differences.

Another use of Smith's work lies in apportioning energy costs between different levels of treatment. At a conventional trickling filter plant the primary treatment units, including capacity for sludge processing accounts for approximately 70 percent of the total energy requirements. At a conventional activated sludge plant, because of the aeration requirements and increased sludge handling capacity, primary treatment accounts for about 35 percent of the total energy use. Effluent filtration, which is employed at several treatment facilities in the valley, adds 25 and 12 percent for trickling filter and activated sludge plants, respectively.

Using Figures 18 and 19 to estimate missing unit cost and energy requirements, respectively, the total annual energy expenditure for wastewater treatment in the Basin was about 180 tera Joules (TJ) (51×10^6 kilo-Watt·hours (kW·hr)), an average of 0.50 TJ/day (140,000 kW·hr/day). This amounts to approximately one quarter of one percent of the total Willamette Valley electrical use. Reported dollar costs varied from \$0.13/1000m^3 (\$0.51/million gallons (mg)) at a large primary treatment plant to \$60/1000m^3 (\$230/mg) at a small package extended aeration plant. Secondary treatment plants with flows of 3,800 to 110,000m^3/day (1.0 to 30 mgd) generally had electrical costs on the order of \$0.80 to \$6.60/1000m^3 (\$3 - \$25/mg). The total annual electrical cost for municipal wastewater treatment for the Willamette Valley was about \$600,000 for the 1973-74 period.

Before leaving this section on electricity it would be well to ask two questions. First, what are the direct electrical energy requirements of primary treatment, or, said another way, what savings could be realized if secondary treatment was not employed? Allowing lagoons and extended aeration plants to remain unchanged, a "return" to primary treatment at all trickling filter and activated plants would allow a savings of approximately 0.22 TJ/day (62,000 kW·hr/day) or nearly 45 percent. Second, what would be the direct energy impact if all activated sludge systems were replaced by trickling filtration systems? This "change" would bring about savings of about 0.15 TJ/day (41,000 kW·hr/day) or nearly 30 percent. Of course, the environmental impacts of the effluents would be altered in either case but it is clear that secondary treatment requires a significant resource allocation, the environmental impact of which is not normally considered.

Chemicals --- Chlorine is the major chemical employed in wastewater treatment in the Willamette Valley. All domestic sewage treatment plants employ chlorine as a disinfectant, as does one pulp and paper mill where coliform growth is a problem. A variety of other chemicals, such as settling aids or sludge dewatering agents, are occasionally used. The major thrust of investigation in this area (especially energy costs) was aimed at chlorine. Thus, most of the following discussion concerns its manufacture and use.

Chlorine production --- Chlorine is produced in conjunction with caustic soda and hydrogen by electrolytic action on a solution of sodium chloride:

$$2H_2O + 2NaCl \rightarrow Cl_2 + 2NaOH + H_2 .$$

For each part of chlorine, 1.14 parts, by weight, of sodium hydroxide and 0.028 parts of hydrogen are produced.

The two main types of electrolytic cells used commercially are the diaphragm and mercury cells. The past two decades saw a rapid growth in the use of the mercury cell which is capable of producing a higher quality caustic soda than is the diaphragm type. However, the present stringent environmental controls required for mercury have brought this cell's future growth to a standstill; all new plants being planned in this country are of the diaphragm type and technological improvements for it are being intensively sought.[89]

Generally, the diaphragm cell consists of alternating graphite anode plates and asbestos-impregnated steel screen cathodes. The asbestos acts as a membrane, allowing the salt brine to flow to the cathode and preventing back migration of the sodium and hydroxyl ions. Hot, wet chlorine gas is generated at the anode, taken off the top of the cells, cooled with water in counter current packed towers, dried with sulfuric acid, and then compressed and sometimes liquified. A solution ten to fifteen percent in caustic and salt is continuously withdrawn from the bottom of the cell. The solution is concentrated to 50 percent or higher in caustic while most of the salt is precipitated out and used to recharge the cell.[89,90,91]

In the mercury cell chlorine is again formed at the anode; however, a sheet of flowing mercury serves as the cathode. The sodium ions from the brine form an amalgam with the mercury, which is pumped to a separate tank containing water. Here the sodium reacts with the water to form the sodium hydroxide and hydrogen. The caustic solution is much purer than that from the diaphragm cell and much more concentrated, thus requiring less evaporation equipment.[89,90,91]

Energy consumption in chlorine production --- Due to the electrical requirement for cell operation and heat needed in the concentration of the caustic solution, the production of chlorine and caustic is highly energy intensive. Table 22 gives two estimates for energy requirements for their production.

Chemical usage in the Willamette Valley --- A 1967 Bonneville Power Administration (BPA) study[91] estimated chlorine usage for wastewater disinfection in the Pacific Northwest at 1.5 kilograms (kg) (3.2 pounds (lbs)) per person per year. Assuming 0.38m^3 (100 gallons) of sewage per person per day, this works out to about 10 kg/ 1000m^3 (85 lb/mg). The results of the OSU WRRI sewage treatment plant questionnaire showed that more reasonable figures for the Willamette Valley are 5.3 kg/1000m^3 (44 lb/mg) and 7.9 kg/1000m^3 (66 lb/mg) for plants treating more or less than 3,800m^3/day (1 mgd), respectively. These figures put average chlorine use at 5 to 8 mg/l of raw sewage.

Using the actual values reported in the WRRI questionnaire and estimating missing figures employing the 5.3 kg/1000m^3, 7.9 kg/1000m^3, and 0.38m^3 sewage/capita/day values stated above, chlorine consumption for wastewater treatment was approximately 1,800,000 kg (2,000 tons) in 1973. The energy requirement for this amount of chlorine, based on the data in Table 22, could range from 69 to 85 TJ (7.6 to 9.3 x 10^6 kW·hr) depending on the method of production. This amount is equal to between 40 and 45 percent of the electrical needs of all the municipal treatment plants! The cost of chlorine ranged from about $0.02/kg ($0.05/lb) to over $0.09/kg ($0.20/lb). Unit costs varied from $0.50 to $10/1000$m^3$ ($2 to $40/mg), excluding a few plants with very high costs. The total annual chlorine expenditure in the 1973-74 period was about $260,000.

It should be noted that reported (WRRI questionnaire) residual chlorine values in plant effluents range to over ten times the 1.0 mg/l (after 60 minutes detention) requirement of the DEQ. Obviously substantial savings could be realized in this area. Also, some of the ecological problems associated with chlorination (e.g.,toxicity) could be reduced if chlorine application were more closely monitored.

As stated above chlorine is the main chemical used for municipal wastewater treatment. At an individual plant, however, chlorine may account for as little as 10 percent of total chemical costs, although for most plants the figure is in the 70 to 100 percent area. As estimated range for total annual chemical costs is $300,000 to $350,000.

Table 22. ENERGY CONSUMPTION IN CHLORINE MANUFACTURE[a]

Input	Requirements/1,000 kg (2,204.6 lbs)	
	Diaphragm Cell	Mercury Cell
Process Steam		
kg	5,250	245
(lbs)	(11,600)	(540)
Equivalent GJ[b]	16.4	0.77
(Equivalent BTU)[b]	(15.5×10^6)	(0.73×10^6)
Electricity		
GJ[c]	30.5	37.3
(kW·hr)	(3,350)	(4,100)
Total		
GJ	46.9	38.1
(kW·hr)	(5,150)	(4,180)
(BTU)	(44.4×10^6)	(36.0×10^6)

[a] Data from reference 89.

[b] Based on 2950 British Thermal Units (BTU)/kg steam and 1,054.8 J/BTU.

[c] Based on 50% self generated electricity: overall 9.08×10^6 J/kW·hr.

Auxiliary Fuels --- The use of gaseous and liquid fuels in municipal wastewater treatment was researched, but very few data exist on this subject. Fuel use is primarily limited to the heating of anaerobic digesters during periods of low methane production. Usable information on digester gas production was reported by only seven plants. A correlation of gas production to flow and BOD_5 and suspended solids removals was computed and the results are summarized as follows: 22-90m^3 gas/1000m^3 sewage (2,900-12,000 ft^3/mg); 0.14-0.61m^3 gas/kg BOD_5 removed (2.3-8.5 ft^3/lb); and 0.14-0.70m^3 gas/kg suspended solids removed (2.3-9.7 ft^3/lb).

Information existed about auxiliary fuel use at six of these seven plants. Assuming a heat value of 22 MJ/m^3 of gas (600 BTU/ft^3), the methane gas produced at these six plants accounted for 81 - 99 percent of the heat requirement. Auxiliary requirements at these six plants ranged from 4.5 - 160 MJ/1000m^3 wastewater (0.016 - 0.58 x 10^6 BTU/mg). A dozen other plants, where digester performance data was lacking, had requirements from 28 - 2,800 MJ/1000m^3 wastewater (0.10 - 10 x 10^6 BTU/mg).

It is difficult to put a figure on the total basin auxiliary fuel requirement; but, assuming a value of 100 MJ/1000m^3 wastewater (0.36 x 10^6 BTU/mg) to estimate missing figures, the needs of those plants having anaerobic digesters (some have aerobic digestion and at least one employs vacuum filtration on its waste activated sludge) would be approximately 33 TJ/year (31 x 10^9 BTU/year), less than one-tenth of one percent of the gas supplied to the Willamette Valley.

Labor and Maintenance --- Labor and maintenance costs were correlated to flow and plant type and the results are presented in Figures 22 and 23. Labor accounted for approximately 60 percent of total O & M costs; maintenance ranged from 5 to 15 percent of the total.

Total Operation and Maintenance --- Figure 24 is a presentation of total O & M costs for municipal wastewater treatment as related to average daily flow and type of treatment system. Reported unit costs varied from \$6.1/1000m^3 (\$23/mg) to \$340/1000m^3 (\$1,300/mg). Total annual costs for the 1973-74 period amounted to approximately \$6,400,000.

Other Considerations --- Before leaving this section on municipal wastewater treatment, two other aspects, the costs of which are included under total O & M, will be discussed.

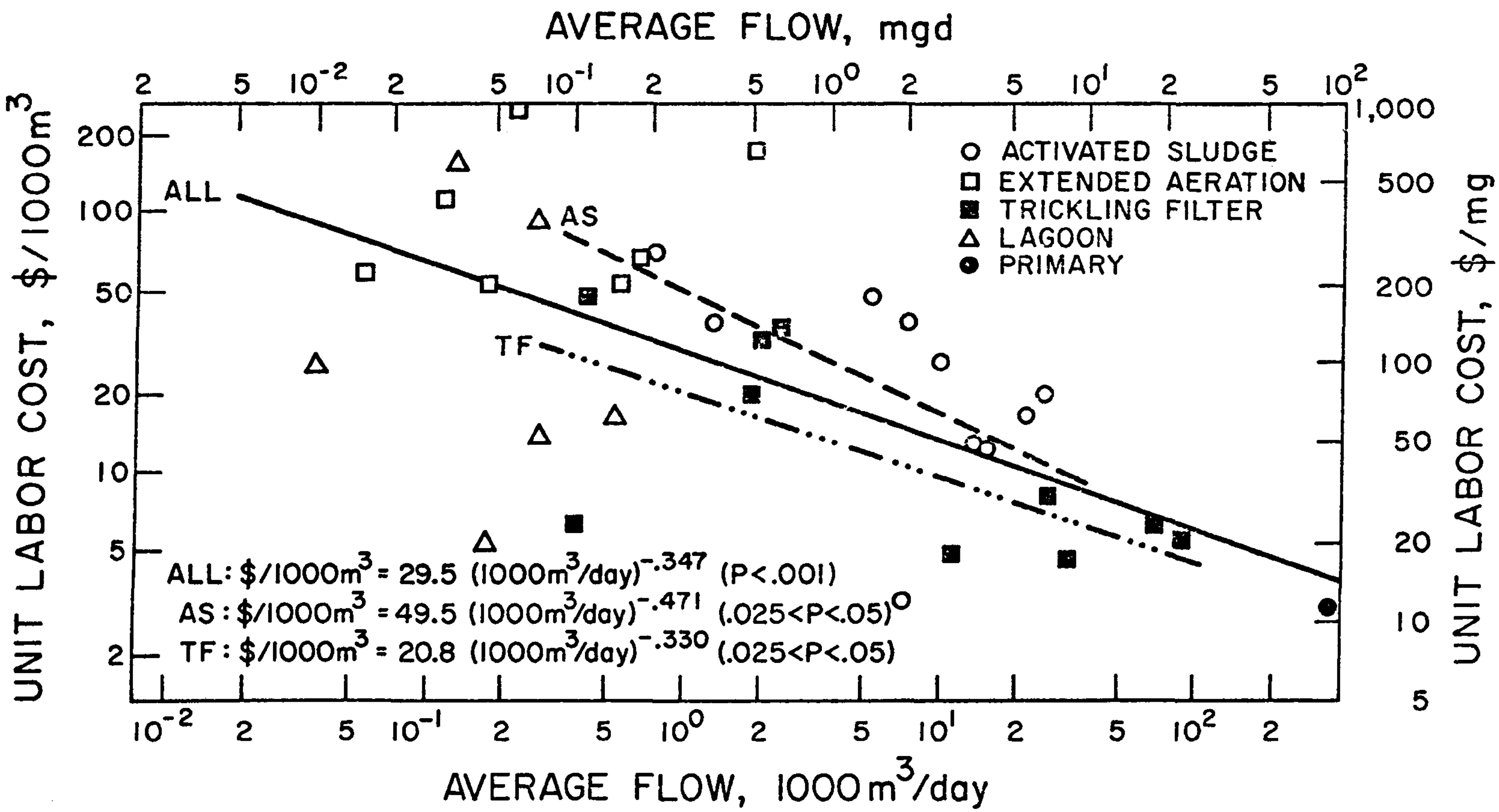

Figure 22. Labor cost vs. flow.

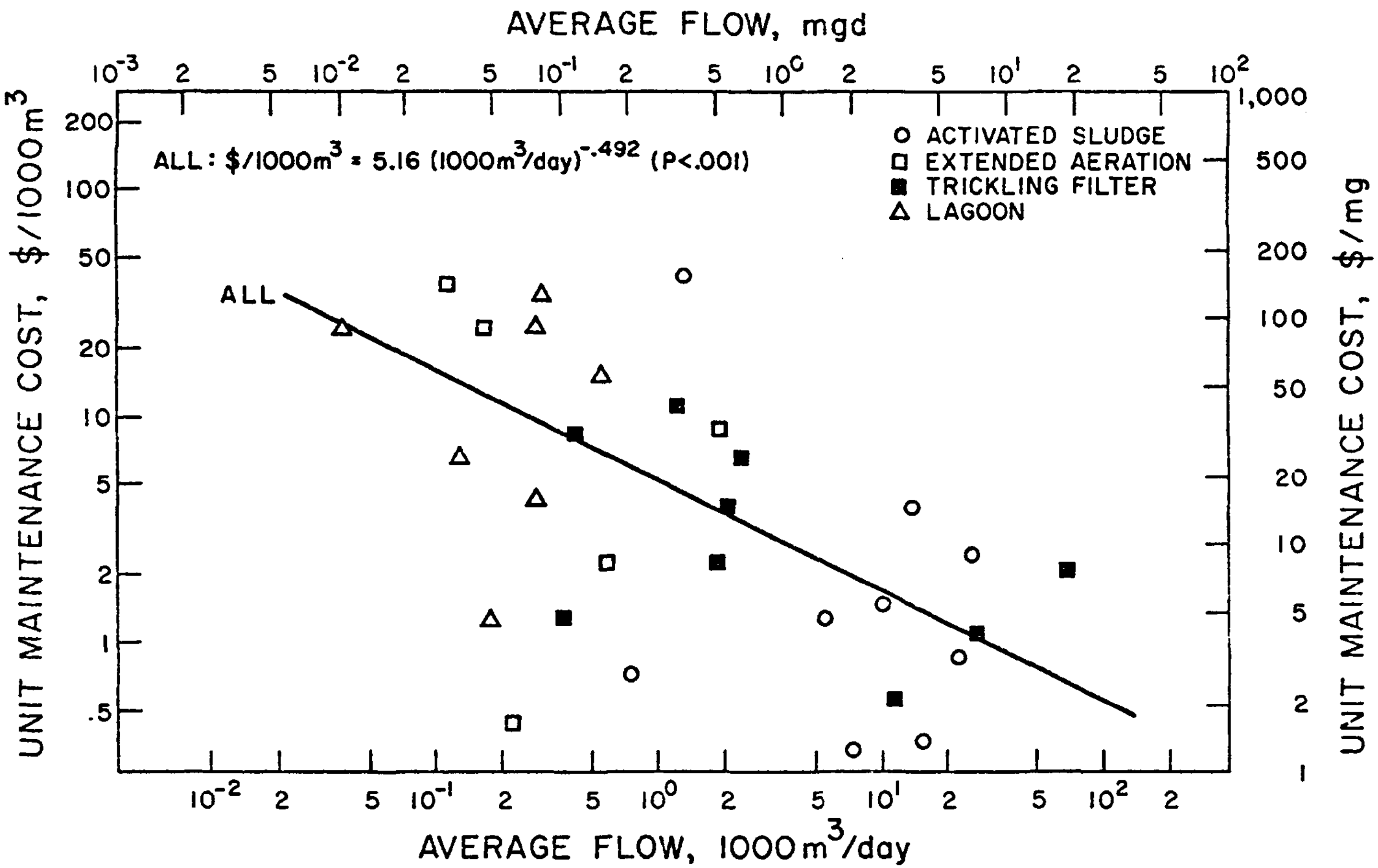

Figure 23. Maintenance cost vs. flow.

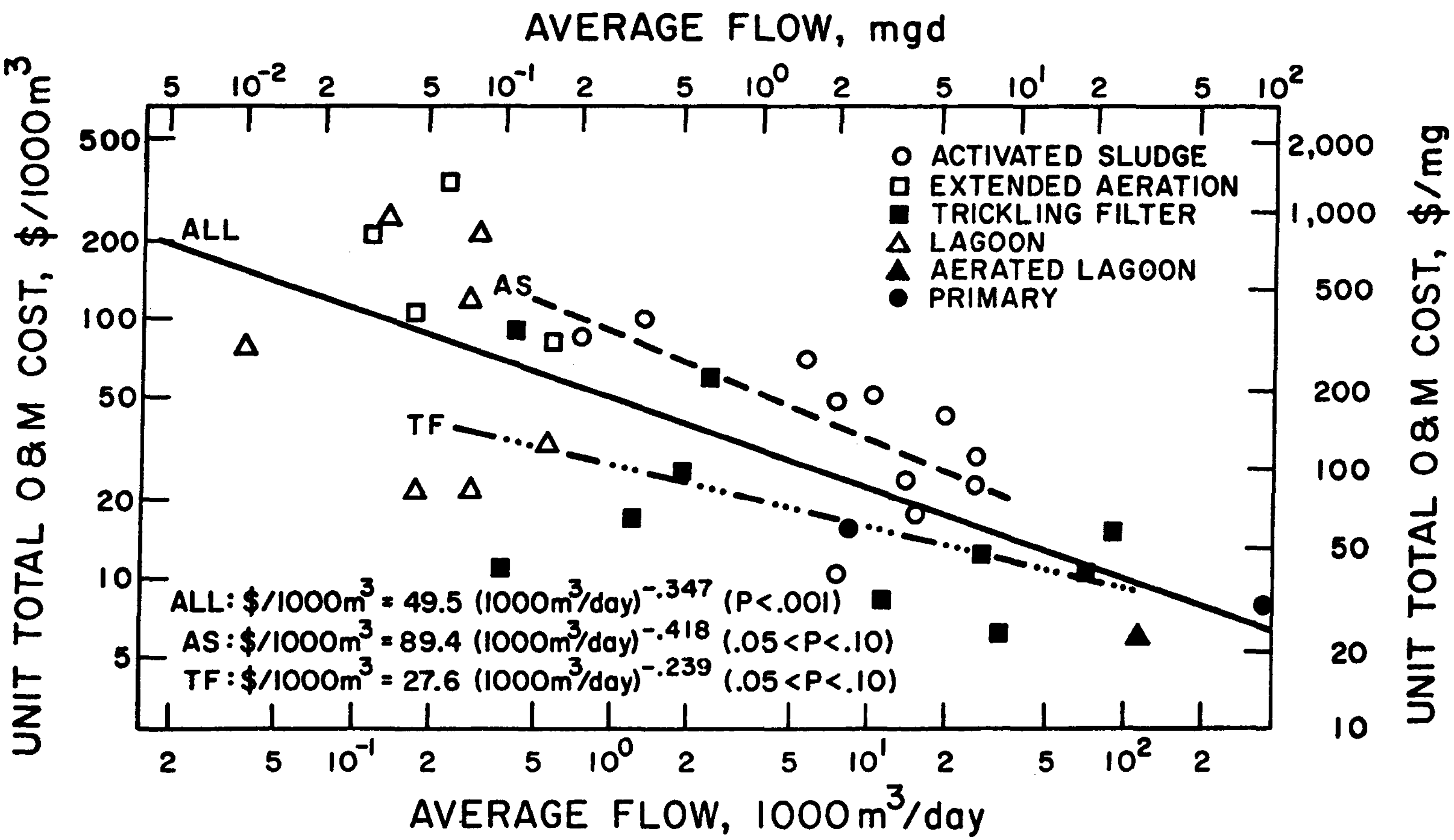

Figure 24. Total operation and maintenance cost vs. flow.

Energy cost of transportation --- The cost of transporting materials which support plant operation is reflected in the materials' purchase price, and this purchase price includes the direct energy needs of transportation. As an example, the energy requirement for chlorine supply was estimated. Using a unit energy figure of 2.490 J/kg·m (3,450 BTU/ton·mile)[92] and assuming that chlorine is produced in Portland and transported an average of 80 km (50 miles), the direct energy required to deliver the 1,800,000 kg of chlorine annually is about 360 MJ, many times less than that required to produce it. For this reason, transport energy costs were not investigated further.

Treatment plant sludge quantities --- The OSU WRRI survey did not include any questions about treatment plant sludges. Except for some spotty information regarding sludge digester operation that is reported monthly to the DEQ, few data exist in this area. Therefore, a textbook[93] approach to this problem was used. Table 23 summarizes the assumptions used. Using these assumptions, which checked fairly well with actual figures at six plants investigated, total municipal sludge production averaged about 130,000 kg (300,000 lbs) per day and amounted to approximately 800,000m^3/year (650 acre ft/year). The majority of this material was applied to open fields; the remainder was landfilled.

Interceptor Systems

Engineers and public works personnel at several communities were contacted in an effort to gain an understanding of the cost of operating and maintaining interceptor lines. The general opinion on maintenance was that interceptor costs represented a relatively small portion of the total costs of maintaining an entire collection system. Most of the problems that arise occur in the smaller sewers and, therefore, most cleaning, inspection, and reconstruction activities are concentrated far "upstream" of the interceptor. Also the majority of the interceptors in the Basin are less than 25 years old and, in general, have required less attention than the older parts of the system. Normal O & M expenditures for interceptors are generally for the running of lift stations and thus depend considerably on topography and flow variation.

Interceptor maintenance --- Due to a near total lack of compiled information regarding existing sewer system parameters (length, diameter, number of lift stations, etc.), it was desired to relate maintenance cost to capital cost. An estimate of 0.4 percent of initial construction cost as an annual maintenance cost for interceptor work was ventured by one city utility representative.[94] Employing this figure on the total construction costs (adjusted to 1973-74 dollars) of the

Table 23. ASSUMED SLUDGE PRODUCTION QUANTITIES[a]

Type of sludge	$kg/1000m^3$	(lb/mg)
Primary-undigested	140	(1200)
Primary-digested	90	(750)
Primary & trickling filter undigested	200	(1700)
Primary & trickling filter digested	140	(1200)
Primary & activated sludge undigested	280	(2300)
Primary & activated sludge digested	170	(1400)
Lagoons-undigested	240	(2000)
Lagoons-digested	170	(1400)
Extended aeration	120	(1000)
Average specific gravity	1.02	
Average moisture content	94%	

[a] Source: reference 93.

interceptor works listed in Table A1 (see Appendix) resulted in an annual cost of about $360,000.

As a verification, the same calculation was performed on the City of Portland's system, yielding a cost of $180,000 per year. (Portland's interceptor capital costs account for one half that of the total basin.) Multiplying Portland's total collection system maintenance budget of 3.5 million dollars by the ratio of interceptor length to total system length yielded a value of $140,000 per year as compared with the $180,000 above, a reasonable check. As the total interceptor maintenance cost of $360,000 per year estimated previously equaled only 5 1/2 percent of total treatment plant O & M, further refinement of the procedure was not attempted.

Lift station O & M --- Just as the pumping of raw wastewater at treatment facilities requires a large amount of electrical energy, so does the operation of lift stations on collection systems. The main difference is that pump stations are much more energy intensive (less labor intensive) than treatment facilities. For example, the four lift stations which comprise Portland's interceptor pumping facilities cost approximately $200,000 per year to operate and maintain, nearly 30 percent of which was for the electrical consumption of about 14 TJ (4.0×10^6 kW·hr). (Portland has a total of 38 pump stations which required approximately 33 TJ (9.2×10^6 kW·hr) of electrical energy for a 12 month period.)

The city's two treatment plants, on the other hand, cost about $1.33 million for O & M and utilized an estimated 11 TJ (3.1×10^6 kW·hr). Thus, it can be seen that truly significant amounts of energy are required to convey waste flows to treatment facilities. It should be noted that Portland is not a "typical" Willamette Basin community. It is large, topography is varied, and most wastewaters are conveyed long distances to the city's larger treatment facility. More "typical" cities are Eugene, where pump station electrical expense, 80 percent of which is for the interceptor portion, is equal to about two-thirds that of the treatment plant, and Salem, which has no pump stations on its interceptor system.

A survey of 15 major sewerage systems, discharging to 27 treatment plants, was carried out in an effort to tie down pumping energy costs. While many cities require varied amounts of pumping in low spots in their systems, only a half dozen municipalities have large interceptor lift stations. Approximately 20 TJ (5.6×10^6 kW·hr) of electricity were utilized operating interceptor lift stations. An estimated 25 to 30 TJ (6.9 to 8.3×10^6 kW·hr) were required for the operation of all other pump stations located on the upper portions of collection systems. The sum of these two figures represents about one-tenth of a percent of the total electrical use in the Willamette Basin. Due to the difficulty of separating collection system maintenance costs, no estimate was made of lift station O & M expenditures.

INDUSTRIAL WASTEWATER TREATMENT

As stated previously, the investigation of industrial expenditures was limited to the twenty firms listed in Table 15. Information regarding O & M costs came from an industrial survey conducted by the OSU WRRI and personal contact with company representatives. Additional information was gathered from the EPA's Development Documents for Effluent Limitation Guidelines. As the pulp and paper industry's share of both waste discharges and expenditures is such a large portion of the total industrial contributions, a section on this industry's costs is presented below.

Pulp and Paper Industry

In each of the following categories, missing expenditure figures for specific firms were estimated using data from other companies having similar processes and waste streams.

Electricity --- Electricity accounts for nearly all of the direct energy use for end-of-the-line wastewater treatment by this industry. Consumption was analyzed and correlated to flow and pollutant removal. The following summarizes the results: 570 - 3,400 MJ/1000m^3 wastewater (600 - 3,600 kW·hr/mg); 4.4 - 11 MJ/kg BOD_5 removed (0.55 - 1.4 kW·hr/lb); and 1.7 - 7.4 MJ/kg suspended solids removed (0.22 - 0.93 kW·hr/lb). Total annual use for the period was about 270 TJ (75 x 10^6 kW·hr), an average of 0.74 TJ/day (210,000 kW·hr/day). These figures represent slightly less than four-tenths of one percent of the total electrical consumption for the Willamette Valley. Total annual electrical costs were about $340,000.

Chemicals --- The pulp and paper industry uses a variety of chemicals, mainly for neutralization and nutrient addition; only one mill, where coliform growth is a problem, chlorinates. Chemical costs totalled approximately $560,000 for the annual period.

Labor and Maintenance --- Salaries and wages were the single most expensive portion of the industry's treatment costs. The annual costs amounted to about $1,100,000, accounting for slightly more than one-third of total O & M costs. Maintenance costs totalled approximately $440,000 for the annual period.

Total Operation and Maintenance --- Total O & M costs for waste stream treatment by the pulp and paper industry amount to $3,000,000 ranging from $1.8 to $11/1000m^3 of wastewater ($7.0 - $40/mg). On the basis of removals, reported costs varied from 0.55¢ to 1.4¢/kg of BOD_5 removed (2.1¢ - 5.2¢/lb) and 0.34¢ to 1.4¢/kg suspended solids removed (1.3¢ - 5.4¢/lb).

Twenty Largest Industrial Firms

The addition of O & M costs of the remaining industries shown in Table 15 to the pulp and paper industry expenditures shown above raises total annual operational costs to approximately $3,500,000. Electricity utilization is increased to about 300 TJ per year (84×10^6 kW·hr/year), about 0.43 percent of the total electrical use in the Willamette Valley.

Again, it should be pointed out that these industrial figures account for expenditures made by only the twenty largest (in terms of waste discharge) firms having their own treatment facilities and outfalls. Excluded are expenditures made by smaller firms with self operated facilities. Also repeating, however, the pulp and paper and related products industry is responsible for about 85 percent of the raw industrial BOD_5 produced and about 95 percent of that discharged.

Excluded, too, are expenditures made by firms discharging to municipal systems. Industrial pretreatment costs were researched. Pretreatment at many companies is an integrated part of the process; therefore, separation of water pollution control costs is generally quite difficult. At those companies where separation of costs was possible, annual operational costs were usually many times less than the sewer charges levied by the municipality. This was expected considering the low level of treatment (e.g., screening, pH adjustment) undertaken. Due to the lack of information, it was not possible to accurately estimate total industrial pretreatment expenditures; however, it was felt that these costs would not significantly increase the 3.5 million dollar figure stated above.

FEDERAL RESERVOIRS

Total Maintenance Costs

Referring to Table 17, it is seen that in Fiscal Year 1972, 2.9 million dollars were spent for maintenance at the 13 existing federal reservoirs. Assuming that water quality control (WQC) "accounts" for 3 percent of the total, as was done in Section VII for capital costs, the WQC benefit "cost" approximately $86,000, a small amount when compared to municipal and industrial O & M expenditures.

Energy Expenditures

The direct energy required to operate and maintain the Corps of Engineers' reservoirs for calendar year 1974 amounts to about 30 TJ (6.9×10^6 kW·hr of electricity plus 4.4×10^9 BTU of refined petroleum products).[95] The 3 percent of this value attributed to WQC amounts to approximately 0.9 TJ. At the same time the eight dams with power facilities delivered approximately 7700 TJ (2.1×10^9 kW·hr) to the Bonneville Power Administration for sale to utilities.

TOTAL ENERGETIC EXPENDITURES

Just as the energy associated with the capital cost figures discussed in Section VII was evaluated employing the I-O-energy methodology, the energy embodied in operational expenditures discussed in this section was estimated in the same manner. Table 24 presents the coefficients used in evaluating the energy costs of electricity, chemicals, and maintenance items. Table 25 presents the results of applying these coefficients to municipal and industrial pollution control activities; this table also summarizes the economic and energetic expenditures discussed in this section on O & M.

One item which has been deleted from Table 25 is labor. It is questionable if the energy associated with labor expenditures should be included in the energy analyses. It can be reasoned that energy expenditures associated with labor would occur whether or not the workers were employed in water pollution control activities (or employed at all). For this reason labor energy has been deleted from this report.

Several points should be noted in reference to Table 25. One, it can be seen that industry gets more electrical energy per dollar spent than does local government. This fact points out one of the weaknesses of the I-O-energy methodology: the problem of energy pricing. In this case the model has overestimated direct electrical use by municipalities and underestimated use by industry. A second point is that the methodology has underestimated the direct energy required to make the chemicals. This is most likely because the I-O-energy model lumps many chemicals of varying energy intensiveness together in one sector; chlorine, however, requires large inputs of energy in its manufacture. A third point to be stressed is that, just as with capital expenditures, much

Table 24. COEFFICIENTS USED IN CONVERTING OPERATION AND MAINTENANCE DOLLARS TO ENERGY VALUES[a]

O & M Category	Coefficients, MJ/dollar[b]	
	Direct	Total
Electricity	585.315	832.560
Chemicals	189.518	573.160
Maintenance and repair	26.905	131.321

[a] Source: Reference 84.
electricity - sector 68.01;
chemicals - sector 27.01;
maintenance and repair - sector 12.02;
based upon 1963 dollars.

[b] 1 MJ - 948 BTU.

Table 25. COSTS OF OPERATING AND MAINTAINING THE WATER POLLUTION CONTROL FACILITIES OF THE WILLAMETTE BASIN

Facility classification[a]	O & M cost, 1963 dollars	Energy requirement, TJ,[b] via I-O-energy model		Direct energy requirement, TJ,[b] via calculation
		direct	total	
Municipal facilities				
Treatment plants				
Electricity	450,000	260	370	180
Auxiliary fuel	c	c	c	33
Chemicals	240,000	46	140	69-85[d]
Maintenance and repair	1,200,000	33	160	e
Interceptors, total O & M	270,000	c	c	c
Interceptor lift stations				
Electricity	f	c	c	20
Industrial facilities				
Treatment plants				
Electricity	250,000	150	210	300
Chemicals	420,000	79	240	c
Maintenance and repair	740,000	20	97	e
Reservoirs				
Total				
Electricity	f	c	c	25.0
Petroleum	f	c	c	4.6
Total O & M	2,400,000	c	c	29.6
3% WQC				
Electricity	f	c	c	0.75
Petroleum	f	c	c	0.14
Total O & M	71,000	c	c	0.89

[a] As defined; see text for full description.

[b] 1 TJ = 948×10^6 BTU = 278×10^3 kW·hr.

[c] Not estimated.

[d] Energy to produce chlorine only.

[e] Does not apply.

[f] Not available.

energy is embodied or sequestered in materials. This fact is shown in comparing the direct and total energy coefficients listed in Table 24.

SECTION IX

DISCUSSION

GENERAL

The costs of water quality control facilities are generally measured in economic terms alone. The uses of natural resources, such as energy, and the net impact of treatment technologies on the total physical environment (i.e., the land, air, and water) are rarely evaluated. As a consequence of this approach to environmental management, some problems have been and are being created in pursuit of water quality objectives.

The research previously discussed dealt with identifying those facilities that are primarily responsible for maintaining high quality in the waters of the Willamette Basin, evaluating the environmental impact of the restoration of water quality, and estimating the economic and energetic costs of the cleanup.

Two major reasons for the restoration are identified in investigating the Basin's water quality control facilities. One is the reduction of oxygen demanding substances released in the river and its tributaries. A series of point-source wastewater treatment tactics, that culminated in 1972 with all dischargers employing secondary or higher levels of treatment, is responsible for this reduction. The second is flow augmentation from a network of reservoirs operated by the Corps of Engineers. Average summer flows are now more than twice the levels that occurred prior to the construction of the first impoundment.

The many environmental effects of the restoration are wide ranging. The improvement in water quality is beneficial to river organisms such as fish and is also aesthetically pleasing to both recreationalists and persons residing near the river. There are also negative impacts associated with the cleanup; one example being the loss of free flowing streams when reservoirs are constructed. Such impacts and the "tradeoffs" inherent in environmental protection programs are discussed in Section VI.

EXPENDITURES

The results of the sections regarding capital and operation and maintenance expenditures are summarized in Table 26. Capital costs have been adjusted to 1974 dollars so that a comparison with O & M costs is

Table 26. SUMMARY OF EXPENDITURES FOR WATER POLLUTION CONTROL IN THE WILLAMETTE BASIN.

Facility classification[a]	Capital expenditures			Operation and maintenance expenditures, 1973-1974			
	Construction cost, 1974 dollars	Energy requirements, TJ[b], via I-O-energy model approach		O&M cost, 1974 dollars	Energy requirements, TJ[b], via I-O-energy model approach		Calculated direct energy requirement, TJ[b]
		Direct	Total		Direct	Total	
Municipal facilities							
Treatment works	160,000,000	680	9,200	6,400,000	260[c]	370[c]	210[d]
Interceptors	88,000,000	380	5,100	360,000	e	e	e
Interceptor Lift Stations	e	e	e	e	e	e	20
All facilities	260,000,000	1,100	15,000	e	e	e	e
Industrial facilities	73,000,000	310	4,200	3,500,000	150[c]	210[c]	300
Reservoirs							
Total	1,100,000,000	4,800	65,000	2,900,000[f]	e	e	30
3%-WQC[g]	32,000,000	140	1,900	86,000[f]	e	e	0.9

[a] As defined; see previous sections for full description of facility classification.

[b] 1 TJ = 948 x 10^6 BTU = 278 x 10^3 kW·hr.

[c] Electrical energy only; see Table 18.

[d] 85% electricity and 15% auxiliary fuels.

[e] Not estimated; see text for discussion.

[f] Fiscal Year 1972.

[g] 3% allocated for water quality control.

Note: Energy values via I-O-energy methodology are based upon 1963 dollars.

possible. The reader should use caution, however, in comparing the capital and O & M costs of municipal treatment facilities. First, as stated in Section VII, a portion of the capital costs, accounting for about two percent of all treatment plant capital costs, are for plants which are no longer operating. Secondly, many cities have wholely or partially replaced treatment works at some point in time. No estimate of the importance of this problem was made. These two considerations are very minor in municipal collection and industrial abatement and non-existent in regards to reservoirs.

It can be deduced from Table 26 that if the direct construction energy requirements of municipal and industrial treatment facilities are amortized over a ten to twenty year life span, the resulting values are relatively small when compared to the yearly O & M needs. Amortizing the total capital energy needs of treatment works over the same period yields figures which are large in comparison to the same annual O & M needs. Thus, two conclusions are reached. First, direct energy requirements are not sufficient data on which to base the energy impact of constructing a project. Second, efforts to reduce the energy impact of these facilities could be aimed at both the construction and operational phases.

Due to their capital intensive nature, even the direct construction energy requirements of reservoirs, when amortized over a minimum life of 100 years, are important.

This research project did not address itself to evaluating total sewerage system costs. To give the reader some perspective on this subject, Table 27 presents a breakdown of sewerage costs for five municipalities. It is evident that pumping costs, particularly energetic costs, are important factors to be considered in any wastewater management plan.

It can also be seen that the upper portions of collection systems require significant maintenance expenditures. However, very little research was done on these "upstream" portions for two reasons. First, the gathering of capital cost data would have been extremely difficult due to the extremely long time span over which sewerage systems have been built. Secondly, it can be argued that the collection system above interceptors was built primarily for public health reasons and would exist whether or not interceptors and treatment works, built primarily for water pollution abatement, were constructed.

The energy costs of the water pollution abatement facilities of the Willamette Basin should be compared to total Basin energy use. In 1973, approximately 150,000 TJ of energy in the form of electricity and natural gas (petroleum excluded) were used in the Valley. Comparing this figure to the direct energy figures in Table 26 indicates that water quality control has required relatively small investments in energy resources. This is true for both capital costs, considering that the facilities have been built over a 30 to 40 year period, and operating costs. Total

Table 27. OPERATION AND MAINTENANCE COSTS OF WASTEWATER COLLECTION AND TREATMENT IN FIVE SELECTED CITIES.

City	Annual treatment costs			All collection lines maintenance cost, dollars	All pump station O&M cost, dollars	Lift station electrical energy requirements, TJ[a]	
	Dollars	Electrical energy, TJ[a]	Auxiliary Fuel energy, TJ[a]			All lift stations	Interceptor lift stations
Portland[b]	1,330,000	11[c]	d	3,500,000	470,000[e]	33	14
Salem[b]	520,000	14[c]	1.3	350,000[e]	80,000[e]	d	none
Eugene	280,000	5.4	0.12	d	d	3.6	3.1
Albany	280,000	9.7	1.1	100,000	d	0.47	0.27
Corvallis	130,000	5.0[c]	0.18	120,000	23,000	0.61	0.47

[a] 1 TJ = 948 x 10^6 BTU = 278 x 10^3 kW·hr.

[b] Two plants.

[c] Estimated, knowing unit cost.

[d] Not available.

[e] Estimated.

operational electricity, the major energy need, amounts to 0.7 percent of that used in the Basin.

This is not to say, however, that pollution control plans should be made without regard to the resource allocation required for the plan's various facilities. On the contrary, the increasingly stricter effluent guidelines proposed by regulatory agencies for all dischargers will greatly increase the energy and material requirements for water quality control. Advanced treatment processes (i.e., post-secondary treatment) are, in general, highly energy intensive. According to Hirst,[96] high level advanced waste treatment processes can more than double the electrical requirements of typical activated sludge systems. On top of this must be added large increases in chemicals and other fuels.[97] For this and other reasons, the resource implications of future environmental protection actions must be carefully considered.

It is increasingly important, in this day of awareness regarding resource limitations, that environmental protection programs yield a net improvement to our land, air, and water surroundings, while having a minimum depleting impact upon our stores of natural resources.

SECTION X

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SECTION XI

GLOSSARY

BOD - Biochemical Oxygen Demand

BOD_5 - Biochemical Oxygen Demand, 5 day

BTU - British Thermal Unit

C - Celsius

C of E - Corps of Engineers

DEQ - Department of Environmental Quality

DO - Dissolved Oxygen

EPA - Environmental Protection Agency

EWEB - Eugene Water and Electric Board

F - Fahrenheit

ft - feet

ft^3 - cubit feet

G - giga, 10^9

g - gram

gpd - gallons per day

hr - hour

in - inch

I-O - Input-Output

J - Joule

k - kilo, 10^3

km - kilometer

km^2 - square kilometer

l - liter

lb - pound

m - meter

m^2 - square meter

m^3 - cubic meter

M - Mega, 10^6
mi - mile
mi^2 - square mile
mg - million gallons
mgd - million gallons per day
mg/l - milligrams per liter
ml - milliliter
O&M - operation and maintenance
OSBH - Oregon State Board of Health
OSSA - Oregon State Sanitary Authority
OSU - Oregon State University
PGE - Portland General Electric
ppm - parts per million
s - second
T - tera, 10^{12}
WQC - Water Quality Control
WRRI - Water Resources Research Institute
yr - year

SECTION XII

APPENDICES

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APPENDIX A

CAPITAL COST DATA -

MUNICIPAL WATER POLLUTION CONTROL

See table A1.

Table A1. CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1915	Mt. Angel	Septic Tank	10,000		
1917	Hubbard	Septic Tank	3,000		
1920	WCTU (Farm) Home (Corvallis)	Septic Tank	5,000[d]		
1922	Grande Ronde	Septic Tank	5,000		
1923	Sherwood	Septic Tank	5,000		
1924	Dallas	STP	15,000		2,000
	Woodburn	Septic Tank	10,000		
			25,000		
1925	Forest Grove	STP	25,000		3,000
	Monmouth	STP	10,000		1,000
			35,000		4,000
1928	Carlton	Septic Tank	3,000		
1929	Chemawa Indian School	Septic Tank	10,000		
	Woodburn Boy's Training (MacLaren) School[c]	Septic Tank	2,000		
			12,000		
1936	Banks	Septic Tank	5,000		
	Estacada	STP	7,500		1,000
	Gaston	Septic Tank	5,000		
	Gresham	STP	22,000		3,000
	Hillsboro	STP	54,000		6,000
			93,500		10,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1939	Silverton	STP	29,000[d]		4,000
1941	Clackamas Heights[e]	Septic Tank	5,000[d]		
	Portland Airbase (Port of Portland)[e]	STP	30,000[d]		4,000
	Yamhill County Camp (Eola Village)	STP	15,000		2,000
			50,000		6,000
1942	Camp Adair[e]	STP	118,000		9,000
1943	Corvallis Airport	Imhoff Tanks	10,000[d]		
	Grand Ronde Housing[e]	Septic Tank	10,000		
	Sweet Home Housing	STP	10,000[d]		2,000
	Wood Village[e]	STP	29,000		4,000
			59,000		6,000
1944	Veneta Housing (School)	Septic Tank	5,000[d]		
1947	Cedar Hills	STP	79,100		8,500
	Cedar Mill Park[e]	STP	45,000		5,600
	Dorena Dam[e]	STP	36,000		4,800
	Eugene	Amazon Int 1		82,286	8,800
	Eugene	Amazon Int 2		84,909	9,000
	Eugene	Franklin B. Int		60,041	6,900
	Gresham	STP impr	13,388		2,000
	Manbrin Gardens[e]	STP	35,000		4,700
	Portland	Columbia B. Int		671,600	48,000
	Portland	Columbia Sl Int		459,218	35,000
	Portland	Lombard Int		54,087	6,500
	Portland	St. John's Int		387,849	31,000
			208,488	1,799,990	170,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

Year	System	Type of project[a]	Costs, dollars: Treatment plant[b]	Costs, dollars: Interceptor, out fall, or lift station[b]	Costs, dollars: Engineering[c]
1948	Broadmoore[e]	STP	31,000		4,200
	Detroit Dam[e]	STP	93,800		9,700
	Junction City	STP, LS	82,683		8,900
	Junction City	Out		47,135	5,700
	Meridan Dam[e]	STP	80,000		9,400
	Salem	Int		366,974	30,000
	Sweet Home	STP	105,000		11,000
	Vermont Hills[e]	STP	5,000		1,000
			397,483	414,109	80,000
1949	Beaverton	STP equip	16,378		} 11,000
	Beaverton	STP	95,527		
	Eugene	STP, sewers	108,351		11,000
	Lowell	STP	80,000		8,600
	Mill City	Septic Tank	5,000[d]		
	Milwaukie	Int		35,276	4,700
	Milwaukie	STP	160,000		15,000
	Monmouth	Out		46,697	5,700
	Newberg	STP	77,600		8,400
	Portland	Peninsula Tunnel Int		2,589,133	160,000
	Portland	Out #1		647,748	47,000
	Portland	Gilson-Greeley Int		983,950	66,000
	Portland	STP	980,620		66,000
	Portland	Out #2		761,833	53,000
	Weyerhauser[e]	STP	10,000		1,500
			1,500,000	5,064,637	460,000
1950	Eugene	Out Material		180,687	} 29,000
	Eugene	Out		174,373	
	Scio	STP	5,000[d]		
	Sherwood	STP	70,000		7,800
	Sherwood	Int		15,000	2,200
			75,000	370,060	39,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1951	Cedar Hills	STP add	66,000		7,400
	Corvallis	Int Materials		22,500	16,000
	Corvallis	Int		145,635	
	Corvallis	Int, Out		60,995	7,000
	Independence - Monmouth	STP	84,199		8,900
	Markham School[e]	STP	30,000		4,100
	PhilomatH	STP	99,449		10,000
	Portland	Grand Av. Int		1,701,845	110,000
	Portland	Out Riprap		14,100	2,100
	Portland	Willamette R. X-ing		682,725	49,000
	Salem	STP	666,500		48,000
	Sandy	STP	46,816		6,000
	West Linn	Int, LS		93,579	9,600
	West Linn	STP	46,438		5,900
			1,039,401	2,721,379	280,000
1952	Cottage Grove	Int, Trunk		24,450	3,700
	Cottage Grove	STP	149,130		11,000
	Dallas	STP equip	40,451		13,000
	Dallas	STP	147,766		
	Forest Grove	STP	199,630		15,000
	Gladstone	Int		9,747	1,500
	Hemlock Subdivision	Septic Tank	11,000[d]		
	Lewis & Clark College[e]	STP	30,000		4,100
	McMinnville	STP	254,831		17,000
	Oak Ridge	STP	57,270		6,700
	Oregon City	Int		193,000	17,000
	Oregon City	STP equip	39,000		5,000
	Oswego (Lake)	STP equip	27,793		3,900
	Tualatin Slopes[e]	Septic Tank	2,500		
	Woodburn	Int		45,633	5,600
	Woodburn	STP	79,000		8,600
			1,000,000	272,830	110,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1953	Albany	STP	354,309		29,000
	Albany	Int		326,006	27,000
	Albany	Int, LS		41,477	5,200
	Corvallis	STP	304,000		25,000
	Eugene	STP	735,320		60,870[f]
	Hillsboro	STP impr	65,000		7,300
	Lebanon	STP	219,569		19,000
	Lebanon	STP impr	44,991		5,500
	MacLaren School	STP	37,473		4,900
	Oregon City	STP	116,500		12,000
			1,877,162	367,483	200,000
1954	Aloha-Huber School[e]	STP	10,000		1,500
	Carlton	STP	102,947		11,000
	Eugene	STP impr	12,500		1,800
	Gladstone	Out, LS		57,751	6,700
	Gresham	STP	186,212		17,000
	Laurelwood Academy	STP	33,000		4,500
	Marylhurst	STP	33,000[d]		4,500
	Mt. Angel	STP equip	9,497		11,000
	Mt. Angel	STP	92,864		
	Orient School[e]	STP	10,000		1,500
	Oswego (Lake)	STP	123,095		12,000
	Sheridan	STP	79,143		8,500
	Springfield	STP	257,874		22,000
	Tualatin Hills[e]	STP	51,576		6,200
			1,000,000	57,751	110,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

Year	System	Type of project[a]	Costs, dollars: Treatment plant[b]	Costs, dollars: Interceptor, out fall, or lift station[b]	Costs, dollars: Engineering[c]
1955	Brookford[e]	STP	49,500		6,000
	Canby	STP	39,308		5,000
	Chemawa Indian School	STP	20,000[d]		3,000
	Forest Grove	Outfall		31,863	4,400
	Molalla	STP	101,289		10,000
	Oak Grove School[e]	STP	6,565		1,000
	Southwood Park	STP	46,500		4,200
	West Linn	STP equip	4,800		} 7,100
	West Linn	STP	53,364		
	Willamette Manor[e]	STP	22,000		3,300
			340,000	31,863	44,000
1956	Albany	Int, Sewer		119,702	12,000
	Beaver Acres School[e]	STP	20,000[d]		3,000
	Columbia S.D.[e]	STP	55,000		6,500
	Harrisburg	STP	52,113		6,200
	Jesuit H.S.[e]	STP	17,000		2,500
	Lafayette Trad. Fnd.	STP	30,000[d]		4,100
	Lebanon	STP levee	5,965		1,000
	Mill City	Disposal Field	4,490		
	Pioneer Trailer Park[e]	STP	10,000		1,500
	Raleigh S.D.[e]	STP	53,572		6,300
	Raleighwood S.D.[e]	STP	4,000[d]		1,000
	Sheridan Novitiate	STP	30,000[d]		4,100
	West Tualatin View School[e]	STP	60,000[d]		6,900
			340,000	119,702	55,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1957	Albany	STP impr	11,920		1,500
	Cal Young School[e]	STP	20,640		3,100
	Fannoe Park[e]	STP	5,000[d]		700
	Fir Cove	STP	7,900		1,000
	Lebanon	STP add	37,892		4,800
	Portland	West Cent. Int		168,831	16,000
	Salém	Cross St. Int		34,000	4,500
	Sunset Heights[e]	STP	53,000[d]		6,800
	Tigard	STP	94,000		9,700
	Uplands[e]	STP	8,000[d]		1,200
	Whitford-McKay[e]	STP	54,025		6,400
			290,000	202,831	56,000
1958	Beaverton	STP	59,087		6,900
	Bel-Aire Subdivision[e]	STP	60,000[d]		6,900
	Central Linn H.S.	STP	9,000		1,400
	Connie Acres	Septic Tank	16,000[d]		
	Cornelius	STP	117,129		12,000
	Country Club Homes[e]	Lagoon	3,500[d]		600
	Fairview	Out		81,642	8,800
	Hillsboro	Int, Out, LS		200,000	18,000
	Hillsboro	STP	355,000		29,000
	Judson School[e]	STP	17,000		2,600
	Orchid[e]	STP	9,000[d]		1,400
	St. Helens	Int		160,825	15,000
	St. Helens	STP	173,062		13,000
	Sunset Valley	STP	135,595		10,000
	Twin Oaks School	STP	18,000[d]		2,700
	West Salem	Septic Tank	19,000[d]		
			990,000	442,467	130,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1959	BOMARC (Corvallis)[e]	STP	8,000[d]		1,200
	Corvallis T. P.	STP	14,000		2,100
	Exposition Center (Multnomah Co.)	STP	150,000		11,000
	Furlong[e]	STP	41,000		5,200
	Jesuit H.S.[e]	STP add	18,000		2,700
	Oswego (Lake)	Int, Out, LS		11,990	1,800
	Portland	Int, Out, LS		218,312	19,000
	Raleighwood S.D.[e]	STP add	6,500[d]		1,000
	Riverview Hts.	STP	31,900		4,300
	SAGE (Adair Village)	STP	72,000[d]		7,900
	Salem	Int, Out, LS		38,361	5,000
	Salem	STP add	[g]		
	Wulfers Trailer Park[e]	STP	15,000		2,300
			360,000	268,663	64,000
1960	Dammasch State Hospital	STP	115,000		12,000
	Fanno Creek	STP	569,100		42,000
	Fanno Creek	Fanno Cr. Int		330,354	27,000
	Fanno Creek	Fanno Cr. Int		29,748	4,500
	Lowell Park	STP	7,500[d]		1,100
	Meadowlark School[e]	Lagoon	5,500[d]		800
	Newberg	Out		9,267	1,400
	North Shore Park[e]	STP	11,222		1,700
	Oak Lodge S.D.	Int, Out, LS		86,475	9,100
	Oak Lodge S.D.	STP, LS	375,797		24,000
	Portland	Balch Gulch Out		221,816	20,000
	Rilco Corp.[e]	STP	25,000[d]		3,800
	Royal Highlands	STP	5,000		700
	Tahitian Terrace[e]	STP	13,600		2,000
	Uplands[e]	STP	35,000		4,700
	West Slope	Int.		739,183	52,000
	Westmont[e]	Lagoon	6,000[d]		900
			1,200,000	1,416,843	210,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1961	Beaverton	Int, Out, LS		143,546	14,000
	Cal Young School[e]	STP add	15,000[d]		2,200
	Corvallis Airport	Lagoon	12,081		1,800
	Country Squire Inn	STP	22,000		3,300
	Crêswell	Out,Pressure Mn		21,920	3,300
	Creswell	Lagoon	19,648		2,900
	Creswell	Int, Out, LS		10,800	1,600
	Estacada	Septic Tank	3,000		400
	Eugene	STP add	582,000		50,000[f]
	Fanno Creek	Fanno Cr. Int		91,770	9,500
	Fanno Creek	Fanno Cr. Int-Sylvan Trunk		474,417	37,000
	Milwaukie	Int, Out, LS		12,773	1,900
	Newberg	Int, Out, LS		44,643	5,500
	Oak Acres Trailer Park	STP	15,000		2,200
	Oak Lodge S.D.	Int, Out, LS		72,500	8,000
	Oregon City	LS		24,201	3,600
	Oregon Primate Center	STP	25,000		2,500[f]
	Oswego (Lake)	Int, pipe		161,857	52,000 (both Oswego (Lake) rows)
	Oswego (Lake)	Int		574,105	
	Portland	STP impr	89,428		9,300
	Portland	Int, Out, LS		244,640	21,000
	Springfield	Int, Trunks		1,635,918	100,000
	Springfield	STP add	480,670		36,000
	Tualatin Hills[e]	STP add	4,375		700
	West Hills	STP	21,000		3,200
	West Linn	Int, Out, LS		3,198	500
			1,300,000	3,516,288	370,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

Year	System	Type of project[a]	Costs, dollars: Treatment plant[b]	Costs, dollars: Interceptor, out fall, or lift station[b]	Costs, dollars: Engineering[c]
1962	Beaverton	STP add	129,819		9,900
	Canby	STP add	35,000		4,600
	Cedar Hills	STP add	58,000		6,700
	Dayton	STP	2,530		400
	Estacada	Out		36,517	} 16,000
	Estacada	STP	138,231		}
	Eugene	LS, River Xing		370,000	30,000[f]
	Illahee Hills	Lagoon	12,000[d]		1,800
	Marylhurst	STP	30,000		4,100
	McGlasson Village[e]	STP	10,000		1,500
	Milwaukie	STP add	169,950		16,000
	Newberg	STP add	2,688		400
	Oswego (Lake)	Int. pipe		84,125	} 18,000
	Oswego (Lake)	Int		110,000	}
	Portland-Tryon Creek	Tryon Cr Int #2		218,870	19,000
	Portland-Tryon Creek	Tryon Cr Int #1		267,797	22,000
	Scio	Lagoon, LS	21,118		3,200
	Silverton	STP impr	171,178		12,000
	Sugar Plume[e]	STP	13,000[d]		2,000
	Thunderbird Trailer Park[e]	STP	26,000		3,900
	Willamette Lutheran Homes	STP	6,000[d]		900
			830,000	1,087,309	170,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1963	Aloha S.D.	STP	29,986		4,100
	Bailey Hill School[e]	STP	6,987		1,000
	Corvallis	Mary's R. Int		120,046	12,000
	Gaston	Int		28,685	4,300
	Gaston	STP	56,512		6,600
	Hillsboro Jr. H.S.[e]	STP	23,643		3,500
	Indian Hills[e]	STP	9,000[d]		1,400
	Monmouth	Int		31,339	4,300
	Oregon City	STP add	256,368		22,000
	Oswego (Lake)	Int		330,459	27,000
	Pioneer Villa	STP	5,000[d]		700
	Pleasant Valley School	STP	15,000		2,200
	Portland	Int		50,481	6,100
	Portland	NW 9th Int		100,120	10,000
	Portland Trailer Park	STP	66,000[d]		7,400
	Pugh's Motel[e]	STP	5,000[d]		700
	Salem	STP equip	369,814		48,000
	Salem	Int		1,492,758	96,000
	Salem	STP	2,715,577		160,000
	Stayton	Lagoon	25,602		3,800
	Tektronix	STP	60,000		6,900
	West Linn	STP impr	119,990		
	West Linn	STP equip	5,059		16,000 (West Linn, three rows)
	West Linn	STP add	47,954		
	Woodburn	STP add	227,212		16,000
			4,000,000	2,153,888	460,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1964	Aloha S.D.	Int		282,281	24,000
	Aloha S.D.	STP,LS	655,000		47,000
	Baker Bay (Dorena)[e]	STP	59,000[d]		6,800
	Brownsville	Lagoon	121,620		12,000
	Burright Subdivision	STP	6,000[d]		900
	Chatnicka Heights	STP	29,000[d]		4,000
	Country Squire Inn	Lagoon	38,000		4,900
	Country Squire Inn	STP	18,000		2,700
	Eugene Airport	Lagoon	19,000		2,800
	Fanno Cr.	Whitford Int		11,510	1,700
	Forest Grove	STP impr	535,853		40,000
	Green Peter Dam[e]	STP	10,700		1,600
	Jubitz Truck Stop	STP	5,000[d]		700
	Lafayette	Lagoon	48,868		6,000
	McMinnville	STP add	51,605		6,100
	Monmouth	Lagoon	113,352		11,000
	Oak Hill	STP	80,000[d]		8,600
	Oak Lodge S.D.	Lab, Garage	24,241		1,742[f]
	Oregon Primate Research Center	STP add	16,567		1,657
	Pinebrook S.D.[e]	STP	45,000[d]		5,800
	Pineway Apartments	STP	5,000[d]		700
	Portland	Willamette Int		111,535	12,000
	Portland	Willamette LS		34,950	4,700
	Portland-Tryon Creek	Tryon Cr Int #3		95,356	9,800
	Portland-Tryon Creek	STP	764,702		54,000
	Salem	S. Salem Int		540,225	40,000
	Sheridan	STP	173,000		16,000
	Sherwood	STP add	150,000		14,000
	Somerset West	STP	67,000[d]		7,500
	Sunset Valley	STP impr	258,999		18,000
	Sylvan Heights[e]	STP	5,000[d]		700
	Tigard	Int		93,876	9,700
	Uplands[e]	STP add	39,000[d]		5,000
	West Hills Convalescent Home[e]	STP	9,000[d]		1,400
	Yamhill	STP	67,000		7,500
			3,400,000	1,169,733	390,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1965	Aloha S.D.	Beaverton Cr Int		545,057	40,000
	Chemawa Indian School	STP	66,000[d]		7,400
	Dayton	Lagoon, LS	40,272		5,100
	Diamond Hill	STP	5,000[d]		700
	Eugene	STP add	1,250,000		40,000
	Fanno Creek	Sylvan Int		98,115	10,000
	Gervais	Lagoon, etc.	57,731		6,800
	Hayden Island Mobile Home	STP	22,000[d]		3,300
	King City	STP	40,000		5,100
	MacLaren School[e]	STP add	8,296		1,200
	Metzger S.D.	STP	452,481		35,000
	Metzger S.D.	Int. Ext		330,635	27,000
	Panavista	STP	11,000[d]		1,600
	Peerless Truck Stop[e]	STP	5,000[d]		700
	Portland	Willamette Int #2		267,341	23,000
	Ramada Inn	STP	18,000[d]		2,700
	Salem	Pen. Annex - Fairview Lagoon	25,064		3,800
	Sandy	STP add	11,200		1,700
	Stephenson School	STP	46,000[d]		5,600
	Sweet Home	STP add	30,450		4,200
	Tangent School	STP	12,000[d]		1,800
	Tigard	STP add	181,870		17,000
	Timberlakes Job Corps	STP	30,000		6,000
	Wilark Park[e]	STP	25,000[d]		3,800
			2,300,000	1,241,148	250,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1966	Banks	STP	71,228		7,800
	Corvallis	STP add	1,060,000		70,000
	Cottage Grove	STP add	166,214		15,000
	Cottage Grove	Int, LS		52,557	6,200
	Fanno Creek	Sylvan Int. Ext		65,641	7,400
	Goshen School	Lagoon	9,980		698[f]
	Harrisburg	STP add	53,611		1,500
	Hayden Island Mobile Homes	STP add	22,000[d]		3,300
	Hemlock Subdivision	STP	20,000[d]		3,000
	Independence	Lagoon, LS	112,135		11,000
	Millersburg School	Lagoon	16,902		198[f]
	Portland	Guilds Lake Int		935,528	64,000
	Salem	Int, Trunk		759,280	54,000
	Timberlakes Job Corps	STP add	24,000		3,600
	Willamina	Lagoon	72,800		8,000
			1,600,000	1,813,006	260,000
1967	Amity	Lagoon	48,423		5,900
	Eugene	STP add	9,000		1,400
	Eugene Airport	STP impr	1,800		300
	Fanno Creek	STP add	297,100		25,000
	Hubbard	STP	133,495		20,000
	Junction City	Lagoon, LS	75,300		8,300
	Lane C.C.	Lagoon	26,000[d]		3,900
	Laurelwood Academy	STP impr	[g]		
	Lebanon	West Side Int		164,592	16,000
	Millersburg School	STP impr	2,450		400
	Monroe	Lagoon	61,745		7,400
	Portland	S.E. Division Int		98,085	10,000
	Salemtowne[e]	STP	68,000[d]		7,600
			720,000	262,677	110,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1968	Albany	STP add	2,103,000		130,000
	Amity	Lagoon	48,423		5,900
	Dallas	Int. Ext		338,412	28,000
	Oakridge	STP add, Int. Ext	294,342		25,000
	Portland	Int, Int. Ext		2,632,171	160,000
	Propco	STP	12,000[d]		1,800
	River Village T.P.	STP	5,000[d]		700
	Skyline West	Lagoon	10,000[d]		1,500
			2,500,000	2,970,583	350,000
1969	A. P. Industrial Park	STP	6,500[d]		1,000
	American Can Co.	STP	11,500[d]		1,700
	Halsey	Lagoon	104,615		11,000
	Hillsboro	STP-new	1,433,721		99,000
	Inverness	STP	400,000		32,000
	Jefferson	Lagoon	139,183		14,000
	Mountain States Investment	STP	16,000[d]		2,400
	Portland	STP add	2,664,364		160,000
	Stuckey's Pecan	Lagoon	3,000[d]		400
	Tigard	Int. Ext.		61,587	7,100
	Timberlakes Job Corps	LS, Sewers		46,000	5,000[f]
	West Salem	STP, Int	729,105		51,000
	Dallas	New STP	1,000,000		68,000
			6,500,000	107,587	450,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1970	Aumsville	Lagoon	169,829		16,000
	Dundee	Lagoon	266,427		23,000
	Eugene	STP add	1,156,795		44,000[f]
	Gresham	Int. Ext.		769,106	54,000
	Lake Oswego	Int. Ext.		170,724	16,000
	Lebanon	Int. Ext.		208,141	19,000
	McMinnville	STP add, Int, Ext	1,250,000	122,700	89,000
	Newberg	STP add	761,038		53,000
	Oak Lodge S.D.	STP add	27,864		6,613[f]
	Portland	Int. Ext.		589,349	43,000
	Portland	Int. Ext.		382,576	30,000
	River Bend Mobile Park	STP	49,000[d]		6,000
	Silverton	STP add	[g]		
	Tualatin	STP	315,000[d]		26,000
	Veneta	Lagoon	231,937		20,000
	West Linn	Int. Ext.		338,546	27,000
	Washington Co.	Beaverton Int.Ext		114,700	11,000
			4,200,000	2,695,842	480,000
1971	Albany	Int. Ext.		1,621,850	100,000
	Clackamas Co. (Tri-City)	New STP, Int. Ext	1,067,700		71,000
	Columbia Way Crt.	STP	18,000[d]		2,800
	Fir Cove	Lagoon	11,000[d]		1,600
	Hillsboro	Int. Ext.		997,845	67,000
	Oak Lodge S.D.	STP add	318,209		44,997[f]
	Philomath	STP add	210,348		19,000
	Riverview Mobile Ranch	STP	52,000[d]		6,100
	St. Helens	STP add	2,642,806		160,000
	Sauvie Island Moorage	STP	8,000[d]		1,200
	Scappoose	STP, Int., Out	686,700		49,000
			5,000,000	2,619,695	520,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1972	Canby	STP add, Int. Ext	302,756		25,000
	Century Meadows	STP	53,000[d]		6,300
	Cottage Grove	Int. Ext.		77,144	8,300
	Fanno Creek	Int. Ext.		2,035,400	130,000
	Lake Oswego	Int. Ext.		102,670	10,000
	Sandy	STP	416,000		37,000[f]
	Timberlakes Job Corps	Lab	12,000		2,000[f]
	Wilsonville	STP, Int. Out	773,000		54,000
			1,600,000	2,215,214	270,000
1973	Dikeside Moorage	STP	8,000[d]		1,200
	Gresham	STP, Out	2,831,414		170,000
	Marylhurst	STP impr	1,032		
	Multnomah Co.	Int. Ext.		1,908,125	120,000
	Oak Lodge S.D.	STP add	883,371		91,886[f]
	Portland	Int. Ext.		2,231,510	140,000
	Stayton	STP add	453,200		35,000
	Willow Island Mobile Estates	STP	45,000[d]		5,500
	Woodburn	Lagoon	[g]		
			4,200,000	4,139,635	560,000

Table A1 (continued). CAPITAL EXPENDITURES FOR MUNICIPAL SEWAGE COLLECTION AND TREATMENT

			Costs, dollars		
Year	System	Type of project[a]	Treatment plant[b]	Interceptor, out fall, or lift station[b]	Engineering[c]
1974	Central Linn H.S.	Halsey hookup		39,000	5,000
	Hillsboro	STP add	1,285,000		120,000
	Kellog (Clackamas)	Int, STP	8,647,101		480,000
	Lafayette	STP add	165,000		15,000
	McMinnville	Int. Ext.		243,000	21,000
	Milwaukie	Int. Ext.		900,100	61,000
	Oregon Primate Research Center	STP impr	82,422		10,155 [f]
	Portland	STP add	21,398,600		1,100,000
	Portland	STP impr	1,679,000		100,000
	Sweet Home	STP add	1,152,000		75,000
	Timberlakes Job Corps	STP add			25,000 [f]
	Washington Co.				
	Cedar Mill	Int. Ext.		569,000	42,000
	Durham	STP	24,700,000		1,300,000
	Fanno Creek	Int. Ext.		1,961,000	120,000
	Forest Grove - Cornelius	Int. Ext.		305,000	25,000
	Forest Grove	STP add	2,798,000		170,000
	Sherwood	STP impr	550,000		40,000
	Wood Village	Int. Ext.		231,990	20,000
			62,000,000	4,249,090	3,700,000

[a] Abbreviations: add. - addition; equip. -.equipment; exp. - expansion; ext. - extension; impr. - improvement; Int. - Interceptor; LS - lift station; Out. - outfall; STP - sewage treatment plant.

[b] Figures from state and federal reports or OSU WRRI survey results except as noted by d.

[c] Estimated except as noted by f.

[d] Estimated.

[e] Treatment works no longer operating. Excludes plants which have been replaced at site. Includes only those which have abandoned in favor of a regional plant.

[f] Reported by owner.

[g] Figure not available.

APPENDIX B

MUNICIPAL TREATMENT PLANT DATA

See table B1.

Table B1. 1973-74 OPERATION AND MAINTENANCE DATA: MUNICIPAL SEWAGE TREATMENT PLANTS[a]

Type of plant [b]	Average flow, mgd	Influent BOD/SS, mg/l	Effluent BOD/SS, mg/l	Staffing, $/mg	Chlorine			Electricity		Maintenance, $/mg	Total O&M, $/mg
					Residual, mg/l	Applied, lb/mg	Cost, $/mg	Used, kwh/mg	Cost, $/mg		
P	92.0	162/118	138/51	11.60	0.5				0.51		30.50
P	2.2	81/		40.20		39.4	2.68	82.5	1.90		61.88
AL	29.4		49/76					628.0	6.28		23.18
TF	23.7	212/152	36/39	21.72	1.0	55.8	2.73		2.95		58.34
TF	18.67	288/202	32/32	24.10	1.5	52.5	2.76	227.0	3.41	7.87	41.10
AS	6.80	174/169	19/16	77.50	0.7	38.7	1.97	1070.0	10.40	9.10	114.00
TF	7.14	151/142	47/45	30.74	1.0	44.9	2.51		5.88	4.06	49.38
TF	8.7	103/134	28/24	17.35		23.6	1.42				23.56
AS	5.07	133/	7/11		1.5	25.8					164.00
AS	3.95	150/315	17/30		2.7	49.4	2.72	1204.0	13.24		
AS	2.71	191/470	21/9	104.00	1.9	72.7	4.45	2211.0	24.77	5.67	193.00
AS	1.9	250/250	22/22	148.00	1.0	60.9					188.00
AS	3.64	181/221	12/18	48.53	2.5	33.8	2.13	717.0	8.32	14.68	93.40
AS	1.48		15/14	182.00	2.0	77.0	6.85			4.72	277.00
TF-EF	2.0	231/	21/22		1.5	74.7	5.98				
AS	5.95	149/119	27/24	63.97	1.5	33.3	2.00		8.07	3.18	88.16
AS	2.63	231/	25/		1.4	49.8	2.36	1364.0	15.01		
TF-L	2.87	410/221	9/67			73.2	3.43	510.0	4.39		
AS	4.08	117/137	13/8	47.20						1.34	69.57
AS	1.63	132/	59/44		1.8	60.1	2.83	1352.0	16.90		
TF	3.0	100/	27/	18.22	1.0	30.1	2.29		6.10	2.05	31.74
TF-AS	1.54	183/	24/28		2.3	79.2	3.76		15.61		
AS	2.15	115/115	30/30	148.00	3.0	60.9					188.00
TF	1.7	203/	21/			32.4					
TF-L	.64	182/162	17/17	137.00	2.0	59.9	8.56		10.70	23.11	230.00
TF	1.87	114/78	25/21		2.2	40.2					
AS	1.28	223/104	18/31			59.1					
AL-EF	4.01	140/198	19/21		1.5	62.3	2.84	1760.0	16.20		
EA	.25					80.0					
EA	.329	217/	40/			37.8					
AS	.40	173/170	16/16	220.00	1.8	86.3			17.12		
AS	2.0	80/100	8/8	12.61	0.8	29.5		1120.0	13.26	1.24	40.66

Table B1 (continued). 1973-74 OPERATION AND MAINTENANCE DATA: MUNICIPAL SEWAGE TREATMENT PLANTS

Type of plant [b]	Average flow, mgd	Influent BOD/SS, mg/l	Effluent BOD/SS, mg/l	Staffing, $/mg	Chlorine			Electricity		Maintenance, $/mg	Total O&M, $/mg
					Residual, mg/l	Applied, lb/mg	Cost, $/mg	Used, kwh/mg	Cost, $/mg		
TF	.64					31.0					
TF	.323				2.0	54.2	9.21	77.2	1.90	41.76	67.45
TF	.36	101/152	9/27		3.4	58.3	2.77	968.0	16.00		
EA	.5	150/145	10/11	681.00	1.4	131.6	7.67			32.88	
TF	.211				1.9	76.9					
AS	.44	152/	18/			29.2	4.09				
EA	.153	247/208	9/8	205.00	1.6		9.90		118.00	8.60	314.00
EA	.85	50/48	6/15		2.7						
TF	.12					40.0					
TF	.10			24.65	3.0			583.0	12.67	4.79	43.76
AS	.2	200/175	10/10	266.00	1.5	54.8	11.37	1973.0	31.17	2.74	338.00
TF	.61					25.0	4.50	838.0	15.90		
AL	.19					32.0	4.16		8.90		
L	.149	150/150		63.00		53.8			9.20	57.00	129.00
L	.074		10/12	355.00					6.77	91.32	463.00
TF	.112			186.00	2.0	88.0	13.16	1325.0	23.26	31.84	361.00
EA-EF	.257	362/397	8/10			79.0					
TF	.005					620.0					
L	.034			591.00		48.2	7.40		47.89	24.17	937.00
EA	.069				2.7	71.7					
EA	.107				2.3	45.5	2.09		73.37		
EA	.008						38.00		230.00		
EA-L	.045		20/20	207.00	2.0	219.0	48.71	5666.0	62.37	91.32	412.00
EA-L	.059	350/450	38/55	952.00	2.5	130.0	16.90			1.63	1,300.00
EA	.06					90.0					
EA-L	.015			230.00		390.0	152.00		71.00		
EA	.0148						140.00		680.00		
EA-L	.03			438.00			14.90		219.00	146.00	819.00
L	.079		56/		1.5		13.90		34.68	128.00	830.00
TF	.057	196/161	21/30			78.8					
EA	.066					106.0					
EA-L	.073	107/73	10/14								
EA	.22					160.0					

a Information from OSU WRRI questionnaire and survey of monthly reports submitted to the Department of Environmental Quality.

b Type: AL - Aerated Lagoon; AS - Activated Sludge; EA - Extended Aeration; EF - Effluent Filtration; L - Lagoon P - Primary; TF - Trickling Filter

APPENDIX C

WATER TREATMENT PLANT LOCATION

To date only one city - Corvallis - has constructed a water treatment facility that uses the Willamette River as a source. The other river communities generally employ tributaries as supplies while a few have ground water sources. In many instances where the engineering knowledge existed to purify Willamette River water for drinking and where the economics favored using the river, political and public pressure was applied to opt for alternative sources. This was done for aesthetic reasons and fear of using water which carried wastes from upstream.

A survey of the chemical application records at the H. D. Taylor Water Treatment plant in Corvallis for the period 1955-1973 revealed that economies have been realized in recent years. Whether or not these savings are even partially the result of improved river quality is open to speculation. Figure C1 presents a history of chemical use for the nineteen year period. Note particularly the drop in chlorine, the plant disinfectant, and carbon, used for taste and odor control. There has been a definite drop in coliform organisms in the river during the past decade, which could possibly explain the reduction in chlorine use. Little historical data regarding taste and odor problems exist but the reduction in carbon use roughly corresponds to the installation of secondary treatment at an upstream pulp mill.

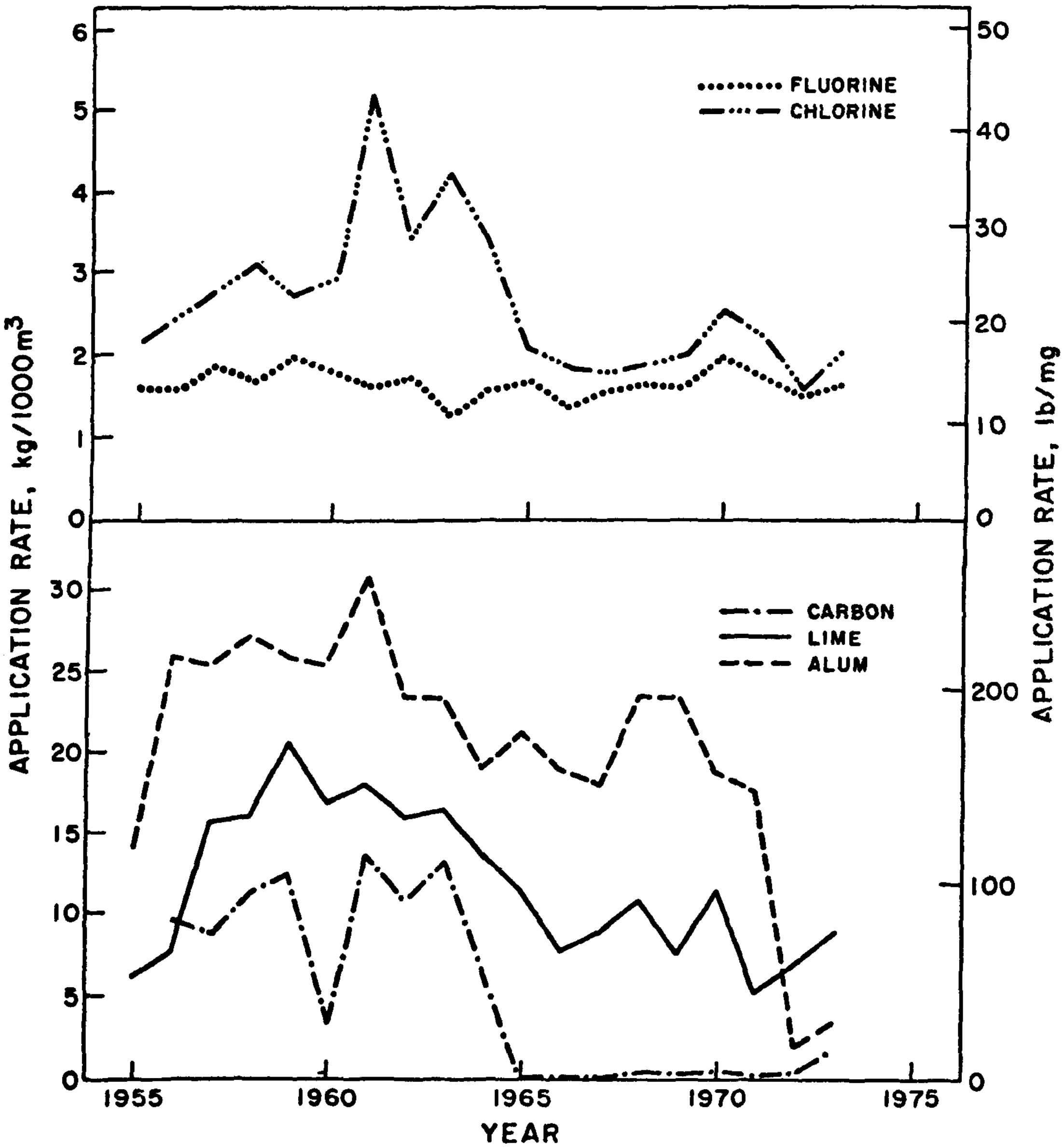

Figure C1. Chemical application history at the H. D. Taylor Water Treatment Plant, Corvallis.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES		

16. ABSTRACT

The means by which the water quality of the Willamette River has been upgraded over the past four decades are documented. Two strategies--point-source wastewater treatment and flow augmentation from a network of federal reservoirs--have been responsible for this improvement ih water quality. The series of tactics employed in gradually reducing point-source waste discharges are documented. Coincident water quality benefits which have resulted from flow augmentation for other purposes are also discussed. The economic and energetic costs of constructing, operating, and maintaining the facilities which have significantly contributed to the improvement of water quality in the Willamette River and its tributaries over the last half century are examined. Data are presented regarding the construction and operation of municipal collection and treatment systems, industrial water pollution abatement facilities, and reservoirs. Input-Output economics and a methodology for converting dollar costs to direct and total energy requirements are used to deal with construction and operational costs. Operation and maintenance expenditures are also dealt with on the basis of direct at-site requirements. Energy needs for operating water quality control facilities are about one-tenth of one percent of total basin energy utilization. Substantial savings of this energy are possible however. Historic and current status of the fishery and wildlife resources of the Willamette River Basin are reviewed in relation to changing water quality of the River. Recent improvements in water quality have stimulated State and Federal agencies to embark on a nine-year program to fully develop the fishery resources of the Basin. The potential biologic, economic, and social values of the program are presented along with related adverse effects attributed to water quality improvement procedures.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Energy Economics Waste water Water treatment Reservoirs Fishes Wildlife	Wastewater treatment plants Flow augmentation Environmental effects Energy analysis Water quality control Willamette River (Oregon)	2B 13B

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