⭧EPA
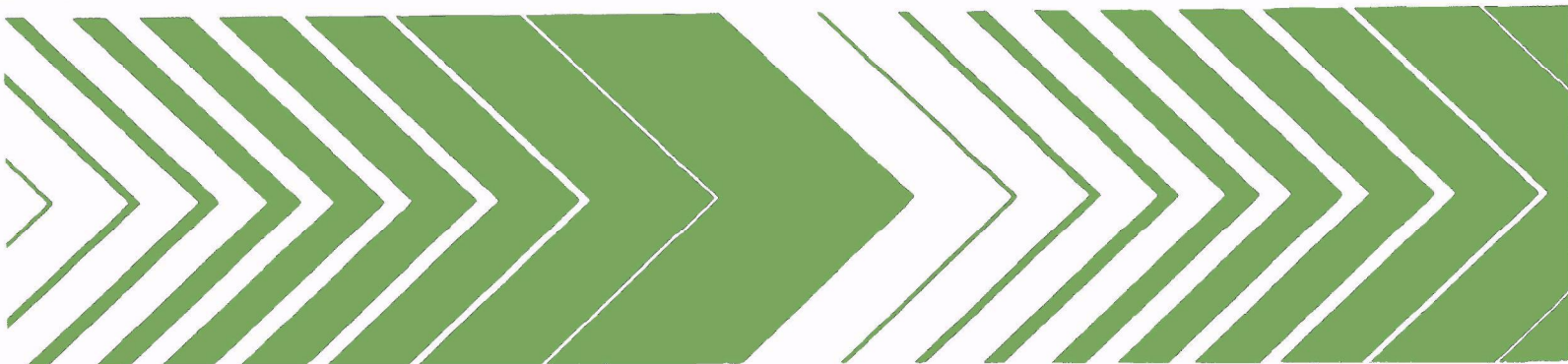
Economic and Energy Analyses of Regional Water Pollution Control

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the SOCIOECONOMIC ENVIRONMENTAL STUDIES series. This series includes research on environmental management, economic analysis, ecological impacts, comprehensive planning and forecasting, and analysis methodologies. Included are tools for determining varying impacts of alternative policies; analyses of environmental planning techniques at the regional, state, and local levels; and approaches to measuring environmental quality perceptions, as well as analysis of ecological and economic impacts of environmental protection measures. Such topics as urban form, industrial mix, growth policies, control, and organizational structure are discussed in terms of optimal environmental performance. These interdisciplinary studies and systems analyses are presented in forms varying from quantitative relational analyses to management and policy-oriented reports.

ECONOMIC AND ENERGY ANALYSES
OF REGIONAL WATER POLLUTION CONTROL

by

Richard J. Heggen
Kenneth J. Williamson
Oregon State University
Corvallis, Oregon 97331

Project Officer

James W. Falco
Technology Development and Applications Branch
Environmental Research Laboratory
Athens, Georgia 30605

ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ATHENS, GEORGIA 30605

DISCLAIMER

This report has been reviewed by the Environmental Research Laboratory, U. S. Environmental Protection Agency, Athens, GA, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

As environmental controls become more costly to implement and the penalties of judgment errors become more severe, environmental quality management requires more efficient analytical tools based on greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental comtaminants, the Technology Development and Applications Branch develops management or engineering tools to help pollution control officials achieve water quality goals through watershed management.

The cleanup of the Willamette River represents a case history of successful regional environmental management based on cooperation between industries and local, state, and Federal governments. In this report, the Willamette Basin is used in a retrospective evaluation of the environmental, economic, and energy consequences of alternative strategies for water pollution control. The investigation serves as a planning example for those concerned with environmental management as environmental quality goals increasingly compete with economic and energy objectives.

David W. Duttweiler
Director
Environmental Research Laboratory
Athens, Georgia

iii

ABSTRACT

Two strategic approaches to water quality control in Oregon's Willamette River are presently being utilized: point source treatment and flow augmentation. Dry weather releases from reservoirs are for authorized purposes other than water quality. However, reservoirs can participate in pollution control by summer flow augmentation if authorized water resource objectives (flood control, navigation, etc.) are not sacrificed.

It is hypothesized that the differences in economic and total energy impacts between treatment and augmentation may be substantial. Of additional interest is the comparison between direct utilization of energy for Willamette Valley pollution control and indirect energy requirements of such programs. Input/output analysis (I/O) provides an econometric methodology to study economic impacts and direct and indirect energy response to pollution control alternatives. In this study, discharge and loadings are empirically related to surveyed direct dollar and energy expenses. An energy I/O national model is coupled with a comprehensive Willamette River dissolved oxygen model. Costs estimated for discharges resulting from different pollution control strategies are then transformed by I/O to total energy costs.

Three approaches to environmental control for the Willamette were examined. One was that of current enforcement coupled with present levels of augmentation. Another consisted of less augmentation and increased wastewater treatment. Appropriate tactics involved advanced secondary methods of treatment, regionalization of treatment plants, and yet more stringent effluent requirements for industry. The third approach consisted of increased flow augmentation for water quality control. Corresponding treatment was somewhat relaxed. Each alternative of environmental control was evaluated as if it had been practiced in a study year of low natural runoff.

The relation of augmentation for water quality to other river uses was utilized to value flow in a benefits-foregone manner. Independently, reservoir costs were allocated to water quality. An instream unit price was thus assigned to augmentation.

For each alternative of treatment and augmentation, the dissolved oxygen quality of the Willamette was simulated and the costs of the environmental strategy estimated. River quality, dollar cost, and energy impact response surfaces were developed. Indirect energy costs, largely expended out of the region, were roughly twice the direct energy use.

Because of the predominance of treatment expenses over augmentation cost and the energy-intensive nature of treatment, energy impact was substantially a reflection of treatment degree. Because augmentation reduced treatment required, energy and dollar efficient management calls for the full role of augmentation in water quality control. In some degree this presently occurs.

Policies of the region were compared; the present commitments to environmental improvement and economic development were found to contradict the area's energy objectives.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGEMENTS

SECTION I

INTRODUCTION

BACKGROUND

The decline in water quality of Oregon's Willamette River and its subsequent restoration have been well documented, both in technical and popular literature (1,2). By 1938 industrial and municipal wastewater discharges in the Willamette Basin had resulted in deterioration of the quality of the Willamette River. During summers, critically low dissolved oxygen concentrations had drastically affected fish migration, aesthetics, and recreation. High fecal bacteria concentrations, floating and benthic sludges, sulfur odors, and infestations of the filamentous bacteria Sphaerotilus had become prevalent.

The State of Oregon through the Oregon State Sanitary Authority (OSSA) began policies in the 1950's to improve water quality on the Willamette River. In 1949 only two primary wastewater plants were completed in the Valley. However, by 1957 all Willamette main stem dischargers except Portland practiced primary treatment. In this same period, the pulp and paper mills had greatly reduced their summer discharges of sulfite waste liquor through lagooning of summer flows, barging to the Columbia, and recovering various byproducts.

In the late 1950's, OSSA began to encourage secondary municipal wastewater treatment. Plants contributing wastes to the most polluted reaches of the river were the first to be upgraded. By the mid-1960's all Willamette Basin municipalities had secondary treatment facilities. Likewise, most industries had improved their effluents to secondary quality by this time.

During the 1950's and 1960's several multipurpose reservoirs were constructed by the U. S. Army Corps of Engineers on the upper Willamette tributaries. Annual drawdown of these facilities significantly augmented the Willamette's summer low flows. As a result, wastes were diluted and transported more rapidly out of the Basin.

Today, the Willamette is noted for its high water quality that was achieved by effective, wide-spread pollution control. The river's cleanup provides a rare case history of successful regional environmental management. Cooperative regulation between industries and local, State, and Federal governments restored the quality of this river in an era when environmental protection was not a popular cause. Because of the general understanding of the recovery of the Willamette River, this river provides a setting in which

1

alternative methods of pollution control can be compared. Various methods of water quality control can be hypothetically proposed, simulated with mathematical modeling, and tested for effectiveness.

It is increasingly recognized that environmental quality is a goal competitive with portions of economic and energy objectives. The three issues, environment, economy, and energy, should be considered simultaneously in a planning process. Whereas the Willamette River has served well as a how-to-cleanup demonstration, its use as a planning example today requires the inclusion of economic and energy dimensions.

In an earlier study of the Willamette River (3), data were compiled dealing with the energy costs of the pollution control techniques applied to the Willamette. Capital and operational costs involved in the cleanup were determined from documents and survey questionnaires. From that work, the total energy consumption for pollution control was estimated and a general understanding emerged of the dollar and energy costs for Willamette water quality control.

STUDY OBJECTIVES

This study extends this earlier work (3), which was an energy and economic inventory, to an economic and energy comparison of water pollution control alternatives. Oregon's environmental, economic, and energy policies are briefly discussed. The environmental, economic, and energy impacts of different approaches to water pollution control on the Willamette River are simulated and compared.

Five objectives are pursued dealing with technical impacts of water pollution control alternatives in the Willamette Basin. They are:
1. To select a representative water quality parameter that can serve as a sensitive indicator of the environmental conditions of the Willamette River;
2. To use this selected water quality parameter to develop a river water quality simulation model;
3. To use the model to quantify the relative environmental effectiveness of each of three water pollution control strategies: the applied strategy of secondary point source treatment and low flow regulation from Federal reservoirs, a strategy directed toward increased treatment, and a strategy directed toward greater reliance on flow augmentation. Each strategy was evaluated for the conditions of 1973, a base year discussed later in this chapter;
4. To estimate the economic cost of attaining several levels of water quality under each strategy; and
5. To estimate the energy cost by Input/Output analysis associated with each strategy and water quality level.

These tasks deal objectively with a real issue of environmental-economic-energy interplay, but the issue also has subjective planning implications. Thus, two additional objectives are pursued, not as technical issues, but to

2

provide this broader perspective. They are:

    6. To identify major Oregon policies dealing with its state-wide environment, economy, and energetics; and
    7. To relate the impacts of the three general strategies of pollution control to these policies.

STUDY DESIGN

Figure 1 illustrates the general procedure of investigation. Roman numerals refer to sections of this report. Parenthetical numbers refer to the study objectives previously listed.

Sections IV and V are of a broad, background nature. These water resources discussions focus on various aspects of Willamette Basin hydrology and development. Later sections on environmental and economic modeling draw from this material. The policies discussed in Section V center on Oregon's environmental, economic and energy goals from which strategies of pollution are ultimately judged.

Environmental, economic, and energy models that are useful for testing and comparing the pollution control strategies are developed in Sections VI, VII and VIII. The first part of each chapter deals with model selection; the remainder deals with model specification.

Section IX, "Analysis," deals with the systematic application of the three models to alternatives for pollution control. In this chapter, the entire technical analysis is traced from identification of pollution control strategy to environmental, economic, and energy impacts.

Section IX draws together the application of the analytical models. Section X relates modeled results to policies established by the State. Section IX is technical, whereas Section X deals with more general implications for comprehensive environmental decision-making.

THE STUDY YEAR

The year 1973 marked a significant point in Willamette water pollution control. Most of the pollution control before this year resulted in water quality improvement. Environmental regulation after this period has been directed toward anticipated future growth. Until 1973, most pollution treatment was achieved by secondary wastewater plants and their industrial equivalents. Costs for such control can be estimated with reasonable accuracy. Sensitivity of both water quality and economic cost to the pollution control strategy allowed strategic alternatives to be compared for this year.

August 1973 illustrates critical hydrologic conditions brought on by a 25-year-low summer flow. Reservoirs were effectively used to maintain aerobic river quality suitable for fish migration. The value of the augmentation can be estimated from realized, not supposed, water quality conditions. Data gathered by the U.S. Geological Survey plus records of Oregon's Department of Environmental Quality (DEQ, successor to the OSSA) independently documented this period.
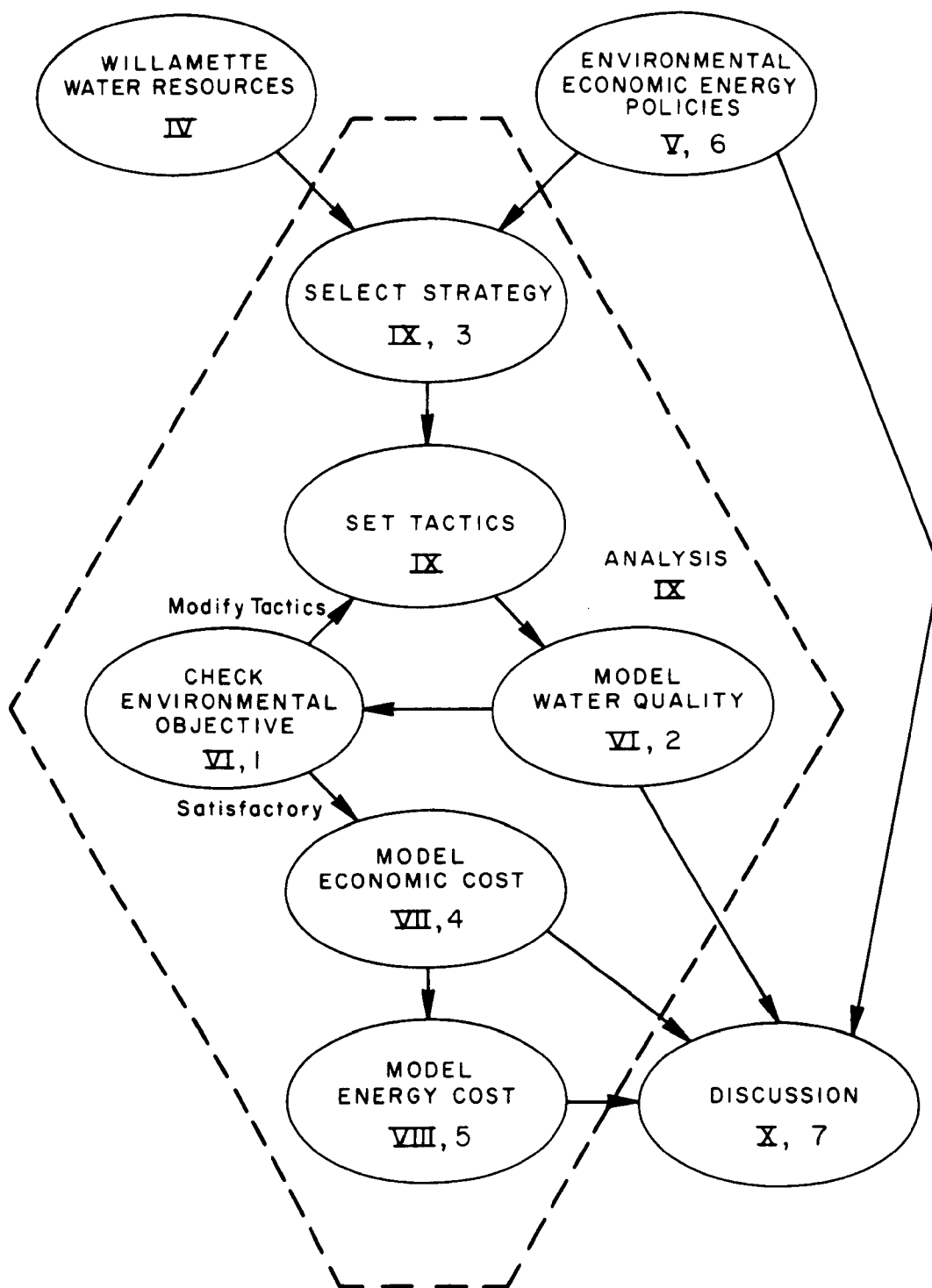
Figure 1. Study schematic.

This study deals with alternative ways in which 1973 conditions could have been managed. For example, flows from reservoirs could have been increased or decreased. Construction of wastewater treatment facilities before 1973 could have been accelerated, achieving higher waste removal, or could have proceeded less rapidly, accomplishing somewhat less point source treatment by 1973. These are the trade-offs that are examined in this study for the Willamette River.

This study is not a projection in time. Some likelihoods about the future might be summarized from the analysis, but extrapolations, at best, should be done with caution. The best employment of this study is that of retrospective analysis. The relationship of energy to dollars illustrates the dual price paid for pollution management. The relationship of both these costs to environmental consequences illustrates returns from investments. The dollar and energy relationships between tactics of environmental control illustrate the sensitivity of environmental quality to pollution control methods.

SECTION II

CONCLUSIONS

The two-pronged strategy of water quality control has restored the environmental quality of Oregon's Willamette River to a well-oxygenated waterway that supports anadromous fish. This strategy employed abatement of municipal and industrial discharges and increased low flow augmentation from Federal reservoirs. The Willamette River presently provides Oregon's residents with a variety of services possible from the preservation of its natural resources. It is a prime State concern that the high environmental quality on the Willamette is maintained. Whereas the Willamette was restored at a dollar cost that Oregonians were willing to pay, the energy investment was considered little in the decision-making process.

This investigation examined the environmental, economic, and energy consequences of various strategies for environmental management. These strategies considered varying degrees of both point source treatment and low flow augmentation. Based on this study, the following conclusions were reached.

1. Water quality control in the Willamette Basin was estimated to have cost $33 million annually in 1973. Of this total, $6 million was spent to divert and treat the Basin's wastewaters to outfalls other than on the Willamette, $3 million represented the water quality benefits of low flow augmentation, and $12 million was spent by the industrial and by the municipal sectors, respectively, for treatment. Of the $30 million spent for waste treatment, $8 million was used for operation, maintenance, and replacement (OMR) and $22 million was the annualized portion of capital costs.

2. The use of existing reservoirs for high, but not maximized, releases for water quality protection represented a reasonably cost effective environmental strategy. Depending upon the method of assigning costs of flow augmentation, savings of $2 to $4 million per year might have occurred if augmentation from existing reservoirs had been increased and offsetting treatment investment foregone. However, if the reservoirs had not been employed, an additional $7 million annually would have been required for treatment to have achieved the 1973 low flow dissolved oxygen quality.

3. Low flow augmentation was particularly effective in maintaining summertime dissolved oxygen (DO) in the Willamette River. Some specific advanced secondary tactics may exist that would benefit summertime DO quality more effectively than maximized augmentation if reservoir releases had large alternative value for irrigation. If wastewaters had been treated in 1973 at advanced levels, augmentation from existing reservoirs should have been maximized for summertime DO quality for any reasonable price of augmentation waters.

6

4.   A unit price of $3/af (acre-foot, 1233 m^3) for summer releases from reservoirs reasonably approximated the value of that water for pollution control if water quality was measured by summertime, 25-year low flow DO levels. Thus, if waters were valued for irrigation at less than $3/af, greater benefits would result if the flows were left instream to dilute wastes and to decrease river travel time. If reservoir releases diverted to agriculture are valued at $20/af, maximum net benefit to the Willamette Basin would occur with maximum use of secondary waste treatment and with only natural river discharges.

5.   In 1973, 510 TJ (terajoule, 948 x 10^6 Btu) of direct energy were consumed for Willamette pollution control. Direct energy is defined as the fossil fuel equivalent of fuels and electricity consumed at the site for point source control or flow agumentation. The reservoir costs associated with water quality benefits, which were allocated by savings in year-around point source facilities to control summertime DO, were 37 TJ. Of the 473 TJ used for treatment, 86 were used to halt discharges to the Willamette and 387 were used to treat discharges. Industrial pollution control required 166 TJ and municipalities required 307 TJ. For pollution control, 363 TJ were consumed in operation and 147 TJ represented the fuels used for annualized construction. Energy use for water pollution control in the Willamette Valley accounted for 0.1 to 0.2 percent of the regional direct energy consumption.

6.   In 1973, 1373 primary TJ were required to directly and indirectly support Willamette pollution regulation. This primary energy value is the fossil fuel requirement of the economy to produce both the direct energy and the materials consumed. Primary energy does not incorporate many energy consequences of pollution control, such as the changed productivity of a valley inundated by a reservoir or a forest harvested to foster economic production to pay for pollution control. Primary energy, which is defined in terms of fuels mined from the earth, is the more traditional planning parameter. The reservoirs' share of this primary total was 120 TJ. Of the 1253 TJ needed for treatment tactics, 515 TJ were used by industries and 738 TJ by municipalities.

7.   Dollar-to-energy coefficients derived from Input/Output analysis varied with pollution control activities. Treatment plant construction typically used 0.8 times as many direct joules per dollar as reservoir construction, but 1.4 times as many primary joules. Treatment plant OMR used 3.2 times as much direct energy per dollar as did reservoir OMR. Plant OMR required 2.9 times as much total energy per dollar as did reservoirs.

8.   For every unit of direct energy consumed in Willamette pollution control, approximately an additional 1.7 units were consumed indirectly. Thus for a typical pollution control activity consuming 10 TJ of energy at the site (7 TJ to build the facility and another 3 TJ for OMR, for example), an additional 17 TJ were consumed for the required construction and operation materials. The primary energy cost for this activity would be 27 TJ. The ratio of indirect and direct estimates varied with activities. For construction of treatment plants it was nearly 5.0; for OMR, 0.7. For construction and OMR of reservoirs, the ratios were 2.3 and 0.9, respectively.

7

9. Although Input/Output energy analysis improves the scope of environmental decisions over those based solely on dollars, it does not appear that this energy analysis gives results substantially different than dollar-valued conclusions. This conclusion stemmed from the strong dependence of energy Input/Output expressions upon dollar data.

10. Energy costs, like dollar costs, were shown to substantially vary with environmental strategy. Of particular relevance in a time of primary energy scarcity is the prediction that energy requirements could double for pollution control if higher-than-secondary wastewater treatment was required uniformly.

11. Oregon's environmental, economic, and energy policies are not entirely reconciled with one another. The restoration of the Willamette's DO was in harmony with environmental policies. The dollar expense for this cleanup was willingly paid by Oregonians and the net effect was an immediate economic advantage to the Basin. The energy costs required for water pollution control, however, were drains on fossil reserves for the Basin's economy. Summertime DO was purchased with fossil fuels likely needed for long-term economic growth.

SECTION III

RECOMMENDATIONS

METHODOLOGICAL RECOMMENDATIONS

1.   Energy analysis of alternative environmental strategies is most like-
ly to bring new perspective to decision making if the alternatives are select-
ed so that equivalent environmental states have substantially different energy
requirements. Such a method identifies energy-efficient environmental control,
but does not impose a technical solution on the tradeoffs between energy and
environmental quality.

2.   Energy analysis of public decisions may be undertaken in direct and/
or primary terms. In a region where local supply of energy is limited, but
extraregional energy supply is great, analysis should center on direct energy
requirements. In a region where energy may be imported as needed, but where
the stock for imports is being exhausted, energy analysis should be in primary
units. In a region where there is local competition for energy and where the
total energy stock is being reduced, analyses should include both measure of
energy.

3.   Input/Output energy analysis is inappropriate when rapidly changing
economic organization and technology occurs. In this study, effort was made
to establish study bounds close to actual, documented conditions. Input/Out-
put models should not be employed in investigations where verification is un-
substantiated.

4.   Input/Output energy analysis should be employed to distinguish be-
tween planning strategies only when the alternatives represent substantially
different predominant tactics and those tactics are of significantly different
energy impacts. Input/Output energy analysis should not be employed to dis-
tinguish between strategies differentiated only by tradeoff of one tactic
and the environment since the same analysis can be made more directly in
dollar terms.

5.   Energy and economic Input/Output analysis of regional environmental
issues may use nationally based data if regional disconformity is shown to be
minor in the sectors of direct interest. The alternative approach of devel-
oping a complete and unique regional I/O data base is likely to be too data-
sparse for planning purposes.

6.   Studies employing Input/Output models must properly conform econom-
ic activities of interest with sectors established for the model. Pollution
control exemplifies an activity that is not readily expressed as an explicit

economic endeavor, but rather must be approximated by several, more general I/O sectors.

7.   River modeling should emphasize simple expressions, data suited to the modeling enterprise, and familiarity with the problem. Complex models built upon data taken for other objectives are likely to be of little value to the decision maker.

POLLUTION CONTROL RECOMMENDATIONS

8.   Water quality planners for the Willamette should adopt a water quality model that they themselves can evaluate and modify.

9.   Federal reservoir cost allocation procedures should afford full credit for water quality improvement to multipurpose water resource projects. In such a way, environmental control may be made more cost-effective. In lieu of a reallocation of existing Willamette projects, a unit price of $3/af should be assigned to reservoir releases for late summer flow augmentation where summertime DO is the environmental objective and alternative points source control tactics call for advanced secondary treatment operated on a year-around basis. This unit price is not proposed for the evaluation of additional reservoir capacity since the marginal returns of new construction should be evaluated only after existing facilities are efficiently operated.

10.   Willamette DO standards should be evaluated in terms of both regional and national dollar and energy costs.

11.   If low flow Willamette augmentation is used efficiently with wastewater treatment, eventually the upper limit of augmentation from existing reservoirs will be required. Water pollution control strategies that propose increased wastewater treatment and source control should be implemented only if the option to increase augmentation is foregone.

12.   Public policies that overlap should be analytically reconciled where possible. Environmental, economic, and energy policies for the Willamette Basin serve as an example. The present environmental and economic policies tend to nullify the energy objectives. An alternative policy perspective is needed from which the policies in harmony with each other, with human welfare, and with nature might be selected.

10

SECTION IV

WATER RESOURCES

INTRODUCTION

The abundant natural resources of Oregon's Willamette River Basin have
made possible the Valley's rapid economic development. The Willamette's waters
provide Valley residents with substantial water services including municipal,
industrial, and agricultural water supply; navigation; hydroelectric power;
flood control; recreation; waste disposal; and fish and wildlife habitat. The
Willamette Basin is today one of the few regions in the United States where
economic growth, water resource development, and environmental considerations
have proven to be reasonably complementary.

This section provides an overview of the Willamette Basin and describes
the present-day character of water resource development.

PHYSICAL SETTING

General Physiography, Geology, and Hydrology

The Willamette Basin (Figure 2) is bounded on the east by the Cascade
Mountains, on the west by Oregon's Coast Range, on the south by the Umpqua
Basin, and on the north by the Columbia River into which the Willamette flows
at Portland. The area of the Willamette Basin is 29,687 square kilometers
(km^2), 31 percent of the state total. Approximately 70 percent of the land is
forest and 30 percent is in agricultural production. Only 5 percent is urban-
ized.

The Basin may be divided physiographically into four sectors: the Coast
Range, the northern Valley, the southern Valley, and the Cascades. The Cas-
cades can be further divided into the lower-lying western Cascades and the
rugged, snowcapped High Cascades (4).

The Coast Range has a crestline rising to 1249 meters (m) and extends to
the Pacific shore. Orographic precipitation from prevailing Pacific wester-
lies feeds short, steep sediment-laden coastal streams. Because the range is
typically low (<500 m) and the westerlies humid and persistently strong, much
precipitation which is condensed in the westerly upwelling is carried over the
Coast Range. The readily available rainfall (typically 1.5 m per year) on
both sides of the Coast Range far exceeds local water requirements except
during the rarest droughts.

The Willamette Valley floor is divided physiographically by the Salem-
Eola Hills. North of these hills, the Valley is composed of non-marine sedi-

11
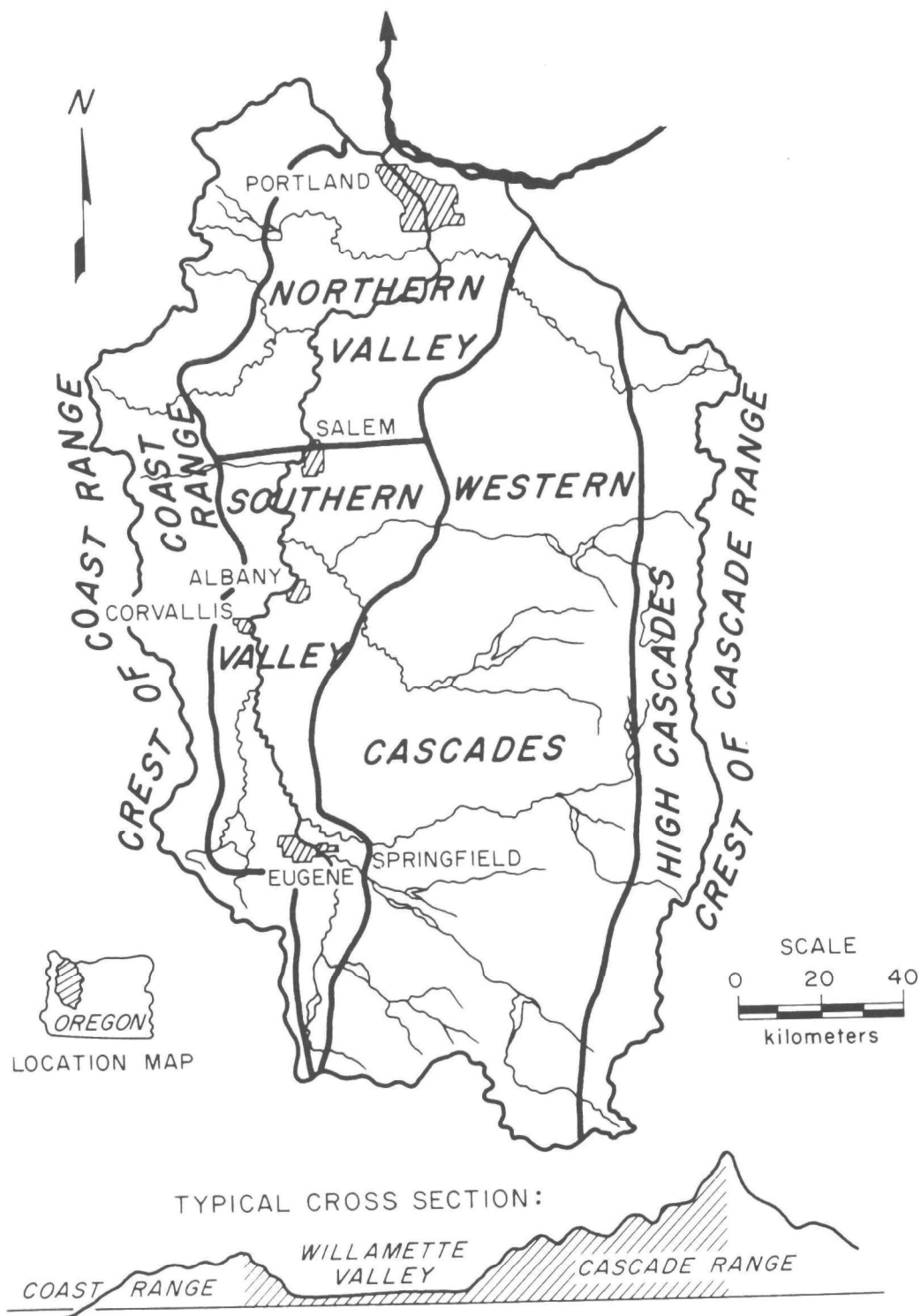
Figure 2. Willamette Basin physiographic sectors and typical cross section (4).

ments and conglomerates. In pre-Pleistocene (ice age) times, the portions of the present-day Willamette Valley bordering the Columbia were extensively built up with Columbia aluvium. At the same time the Willamette, as a lake extending over much of today's Basin floor, deposited a 15 to 30 m bed of sediments. With ice-age sea recession, the lake drained and channels began downcutting and meandering over the alluvial terrace. The northern Valley was again inundated when glacial Lake Missoula broke loose from the Columbia Clark Fork and swept toward the sea 10,000 or 15,000 years ago. The northern Valley has abundant groundwater from the large supply from nearby mountains and the high transmissability due to porous strata of sands and silt.

The southern Willamette Valley floor has experienced similar, but less extensive, sedimentary deposition. Igneous flows and outcrops are common. The southern Valley has redefined its boundaries several times. The Umpqua may have once fed the upper Willamette and the Long Tom may have flowed westward to the Siuslaw and the sea. Gradual weathering of ridges, alluviation, and a rising sea level reduced stream gradients and reoriented channels. Today, the Valley remains broad from Salem to Eugene. Above Eugene a narrow arm of bottom terrain leads up the Coast Fork. As in the north, groundwater is generally available.

Nearly half the Willamette Basin is comprised of the west slope of the Cascades. The Clackamas, Molalla, Santiam, Calapooya, McKenzie, Middle Fork Willamette and Row rivers feed the main stem Willamette from these mountains. The crest line averages somewhat less than 2000 m in altitude with its maximum being 3463 m (Mt. Hood). As the Cascade peaks lie near the eastern boundaries of the mountains, the greater and the wetter portion of the Cascade Range drains west to the Willamette. These western slopes presently support a large timber industry and multiuse Federal and State forests. Slopes are steep, soils are silty-clay, and runoff and infiltration are high.

The High Cascades develop a substantial winter snowpack. Typically the snow is retained until spring when warming temperatures and rain cause rapid melting. Unlike the Columbia, the Willamette snowmelt is completed long before the dry summer months. Even during the dry summer period, however, the discharge of the major Cascade tributaries is substantial.

The Willamette Basin receives abundant rainfall. Fifty percent of the Basin receives 1.5 meters or more of annual precipitation. Seven percent (mountainous regions) experience more than 2.5 m. The driest 1 percent receives 1 m. Runoff is likewise substantial. Fifty percent of the land yields 0.3 meters or less yearly. One percent exceeds 2 m (5). Of the 26 largest rivers in the United States (the Willamette River is fifteenth in annual discharge), the Willamette Basin has the largest runoff/area ratio (0.03 m^3/s·km^2) (6).

The Basin climate is temperature marine. Rain and snow fall during winter and spring; summers and early autumn are clear, dry, and warm. Seventy percent of the annual precipitation occurs from November through March, only about 5 percent during the June-August summer period. The annual range of average monthly temperatures is approximately 14 to 17°C. Extreme daily temperatures for an average winter range from near freezing on the Basin floor to

13

about -8°C in the Cascades. Summer maximums range from approximately 28°C in the Valley to 24°C in the mountains (5).

The Willamette River

The main stem of the Willamette may be divided into three morphological sections as shown in Figure 3. The upstream section, 217 km from Eugene to Newberg, is a relatively steep (0.0005 gradient), braided, shallow (representatively 2 m) erosional regime. Summer velocities are typically 1 meter per second (m/s). From Newberg to the basaltic weir that forms the Willamette Falls (a distance of 41 km), the river is pooled and sluggish. The channel is flatter (0.00001), the depth is greater (7 m), and velocities average approximately 0.2 m/s. Deposition of sediment predominates. Below the Falls (43 km to the Columbia), the river is tidal and during the spring and early summer markedly affected by backwater from the Columbia River. During periods of low Willamette flow, flow reverses twice a day in the lowest reaches which causes water quality in the lowest 8 km to be essentially that of the Columbia River. Depths are maintained at 12 m in the lower 27 km to facilitate navigation. A flat gradient (less than 0.00001) and low velocity (typically 0.1 mps) create a depositional regime (7).

Figure 4 shows inflows to the Willamette for August 1973. Tributaries from the Cascades constitute approximately 90 percent of the summer discharge. Also shown are wastewater discharges.

Thirteen U. S. Army Corps of Engineers reservoirs are located on the southern Willamette Basin tributaries as shown in Table 1 and Figure 5. The reservoirs provide a full pool storage of 2.99 x 10⁹ m³ (2.42 million af). This corresponds to 14 percent of the mean Willamette annual discharge at Salem. As illustrated in Figure 6(a), these reservoirs are operated by draining to low levels to store fall and winter flood flows and storing spring run-off for late summer release. Figure 6(b) shows the corresponding discharge at Salem for 1973 and early 1974.

The marked impact of the reservoirs upon low flow discharge is illustrated in Figure 7, a plot of mean low flows against year. Mass balance analysis of late summer reservoir releases accounts nearly totally for the experienced downstream flow augmentation. Low flows presently are approximately twice the discharge of low flows experienced more than 30 years ago. Figure 7 reveals that hydrologic conditions are typically stable over the low-flow late summer months. The lowest discharge of a single day is not significantly different than the discharge of the driest 30 days.

Basin climate, morphology, and river regulation not only generate characteristic streamflow patterns of the river, but regulate aspects of natural water quality. Precipitation creates high levels of winter turbidity. Eighty percent of the annual sediment load (80 metric tons per square kilometer at Salem) typically is generated from November through February (5). There is relatively little overland runoff or surface erosion during the summer period. Summertime suspended solids concentrations (perhaps 10 mg/l) result in a 2- to 3-meter euphotic zone in the river. This allows the upper section of the main stem to sustain a productive attached population of algae.

14
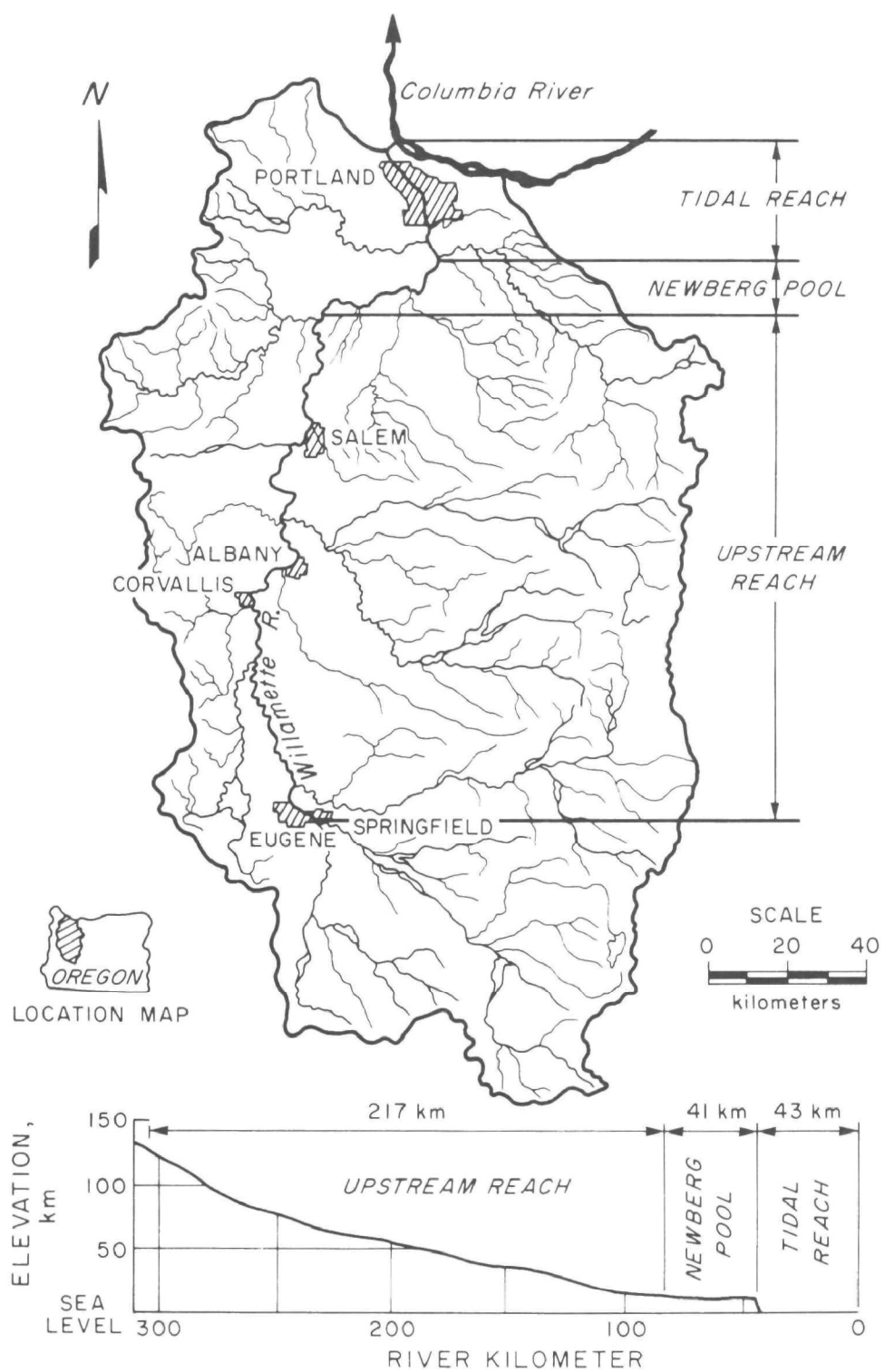
Figure 3. Willamette River geomorphologic reaches (7).
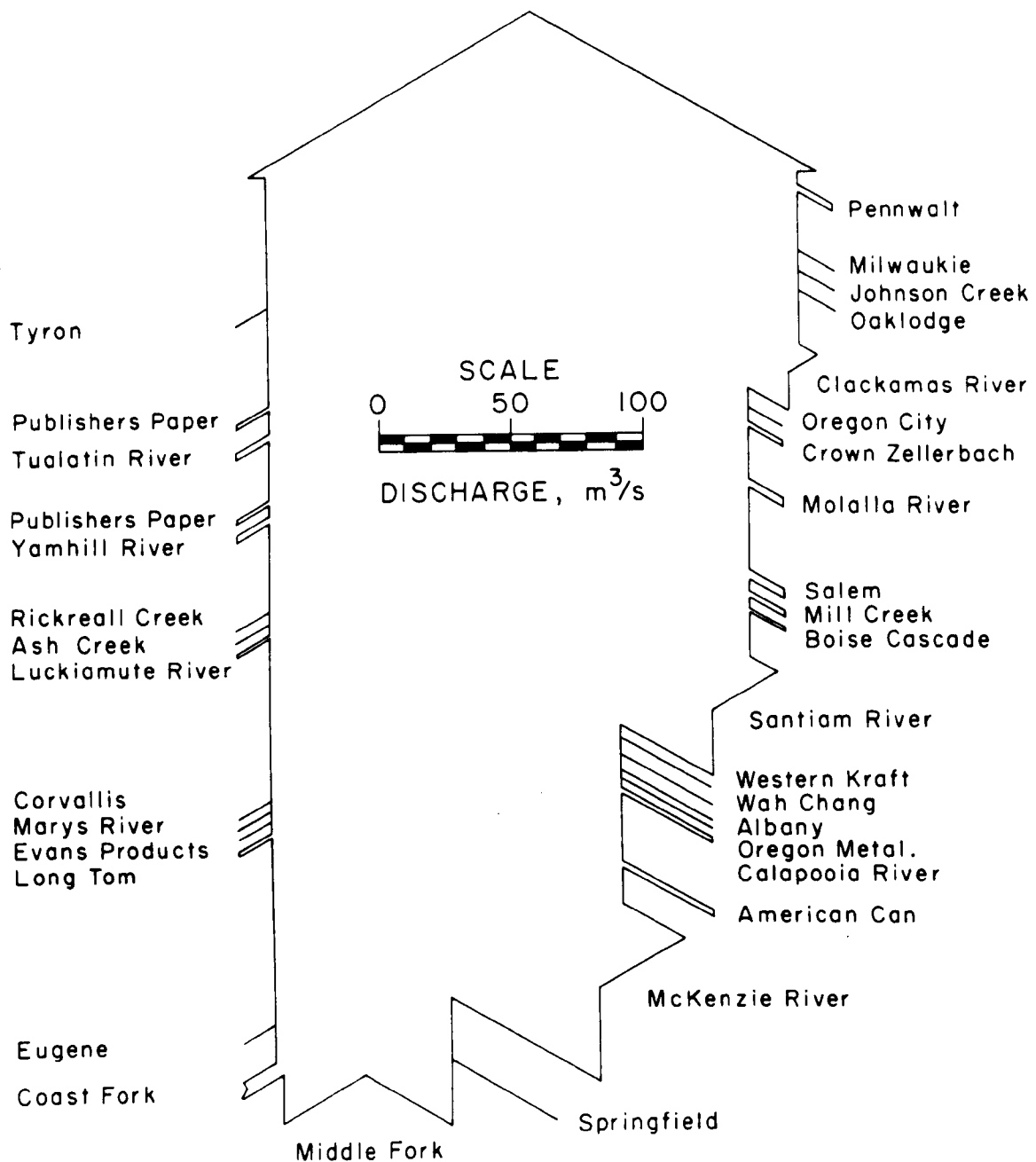
Figure 4. Willamette River flow balance, August 1973 (8, 9, 10).

TABLE 1.   STORAGE RESERVOIRS IN THE WILLAMETTE BASIN WITH 1 MILLION CUBIC METERS OR MORE OF USABLE STORAGE CAPACITY

Rank	Reservoir name	Stream	Operator*	Year placed in operation	Usable Storage $10^6 m^3$	Usable Storage acre ft.	Authorized purposes[+]
1	Lookout Point	Mid Ford Willamette	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	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	84 000	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	Scoggins	Scoggins Cr.	BOR	1975	65	53 800	FC, I, M&I R, F&W, WQ
12	Foster	S. Santiam R.	C of E	1966	41	33 600	FC, P
13	Cottage Grove	Coast Fk. Willamette	C of E	1942	38	30 600	FC, N, I
14	Smith	Smith R.	EWEB	1963	12	9 900	P
15	North Fork	Clackmas R.	PGE	1958	7	6 000	P, R
16	Dexter	Mid Fork Willamette	C of E	1954	6	4 800	P
17	Trail Bridge	McKenzie R.	EWEB	1963	3	2 750	P
18	Big Cliff	N. Santiam R.	C of E	1953	3	2 430	P
19	Dallas	Rickreall Cr.	Dallas	1960	1	1 200	M&I

* C of E=Corps of Engineers; PGE=Portland General Electric; EWEB=Eugene Water & Electric Board; Dallas=City of Dallas; BOR=Bureau of Reclamation

+ FC=flood control; N=navigation; I=irrigation; P=power; R=recreation; M&I=municipal & industrial; F&W=fish and wildlife; WQ=water quality. All existing Federal reservoirs are used for recreation, even though not so authorized.

17
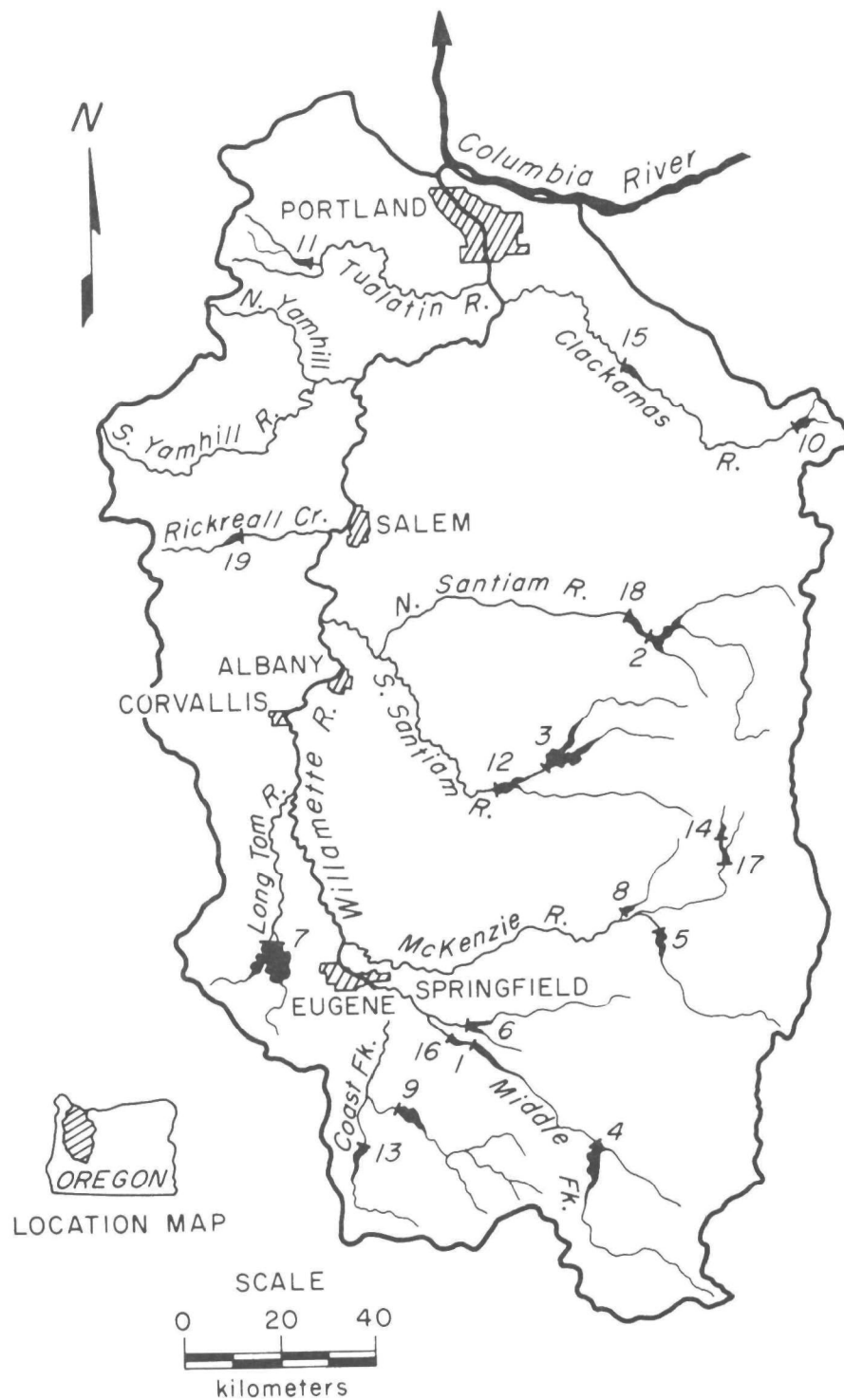
Figure 5. Storage reservoirs in the Willamette Basin (see Table 1 for key).
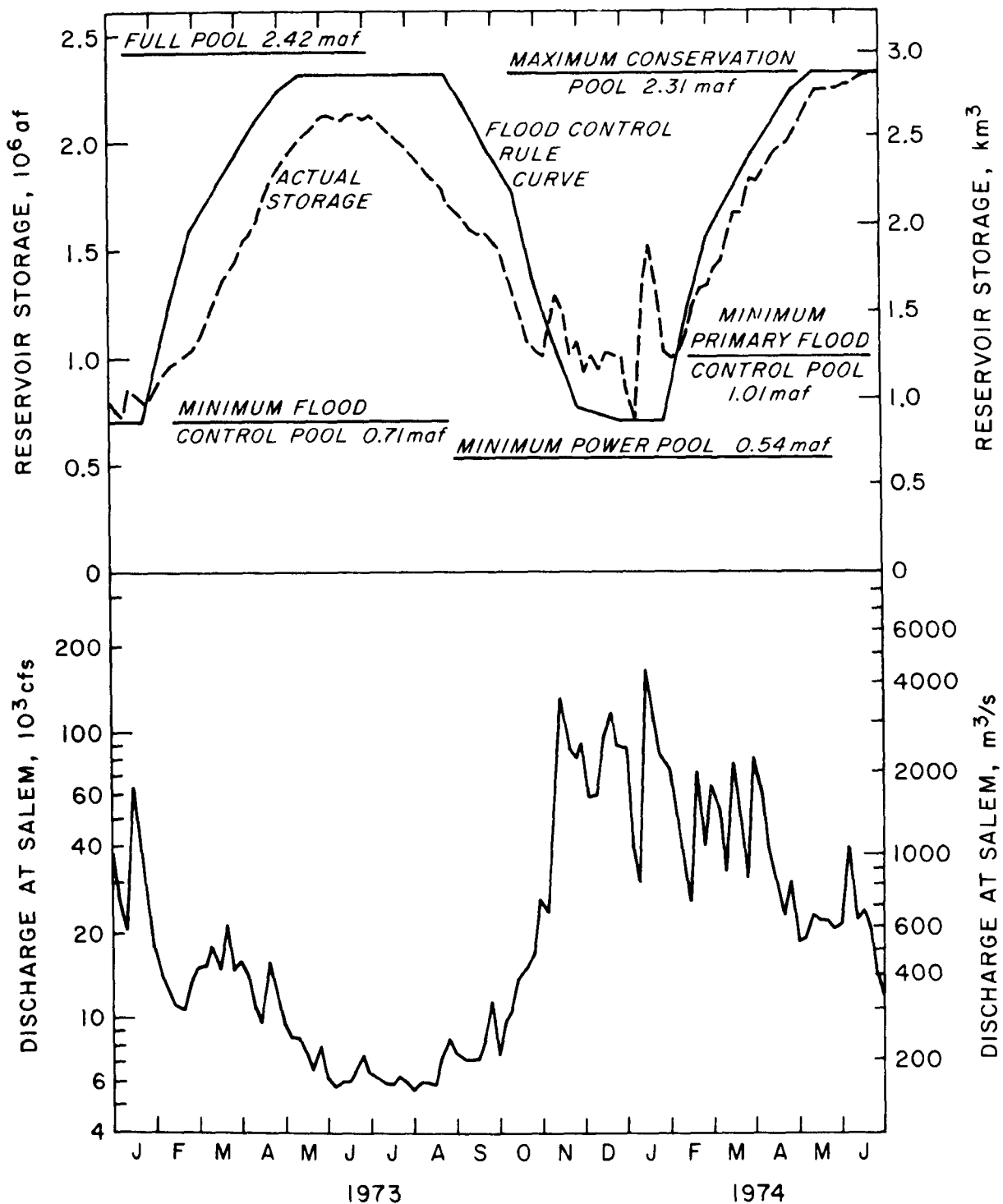
Figure 6. Willamette (a) reservoir rule curve, storage, and
(b) discharge at Salem, 1973-1974 (8, 11, 12).
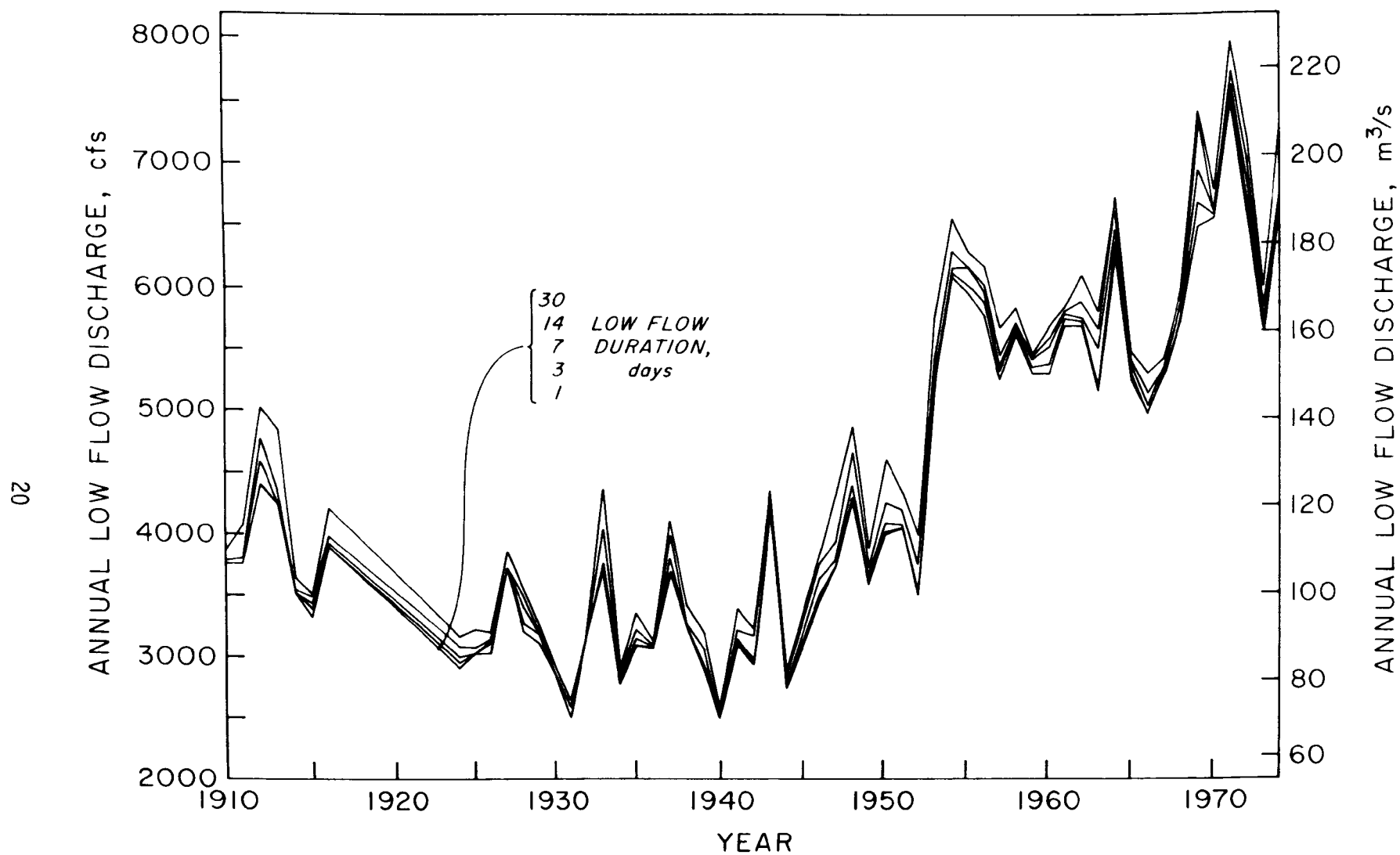
Figure 7. Annual low flow discharge at Salem, 1910-1974 (12).

The temperature of the Basin is reflected in the temperature pattern of the river. The Willamette at Salem averages slightly above 5°C in the winter and approximately 21°C in late summer. The higher temperatures which coincide with lower, summertime streamflow intensify biological rates of oxygen utilization and decrease the water's capacity for dissolved oxygen saturation.

WATER RESOURCES DEVELOPMENT

Municipal and Industrial Water Supply

The water supply for the Basin's major urban areas is drawn from surface sources, but not generally the Willamette River. Of the urban areas listed in Table 2, only Corvallis is supplied from the main stem itself. Minimum main stem use for municipal water supply has come from traditional public hesitation to "drink someone else's sewage." The Willamette presently requires no more than conventional potable water treatment. Valley citizens acknowledge that the river is clean, but subtle prejudice still remains.

Pulp and paper manufacturing provides the Willamette Basin with a relatively stable basic export. Without such an industry, the Basin would experience the hazardous seasonal and financial fluctuations common to raw material economies. This industry requires large quantities of process water, but little is actually consumed. Present pulp and paper water needs require less than 3 percent of the river's minimum annual monthly low flow (10).

Irrigation

Irrigated land has more than doubled in the Willamette Basin in the past 20 years as shown in Figure 8(a). Sixty percent of the irrigation water used is derived from surface sources. More than 10 percent of the lands irrigated from streams receive supplemental supply from reservoir storage. Ninety-nine percent of such storage has additional benefits, principally flood control.

The value of crop and livestock production associated with irrigation in 1964 was $61 million. An economic multiplier encompassing indirect worth of this production is estimated to be 2. Approximately 8600 agricultural workers were employed in irrigated production with an additional 15 000 workers supported in allied industry and services (15, 16, 17).

Navigation

Since territorial days, the Willamette has provided Oregon with a navigation route to its agricultural heartland. Steamboats paddled as far upriver as Eugene. Logs were rafted down tributaries. Opened in 1873, the Willamette Falls Locks (normal total lift - 12.5 m) connect the river reaches. A 2.5-m channel is maintained below the Falls and a 1-m route extends above the Falls to Eugene. Federal expenses for navigation improvement through 1974 were approximately $20 million for locks and $17 million for channel maintenance (18).

The advent of railways, freeways, and pipelines has reduced dependence on river transportation. Over the past 35 years, river traffic has remained fairly constant. Annual haulage is approximately 4 million metric tons, as

TABLE 2. POPULATION CENTERS IN THE WILLAMETTE BASIN (13)

Population center	1976 Population
Portland	382 000
Eugene	96 660
Salem	80 000
Corvallis	40 180
Springfield	35 580
Beaverton	23 300
Albany	22 800
Milwaukie	17 300
Hillsboro	20 100
Lake Oswego	19 700
Estimated basin population	1 588 000
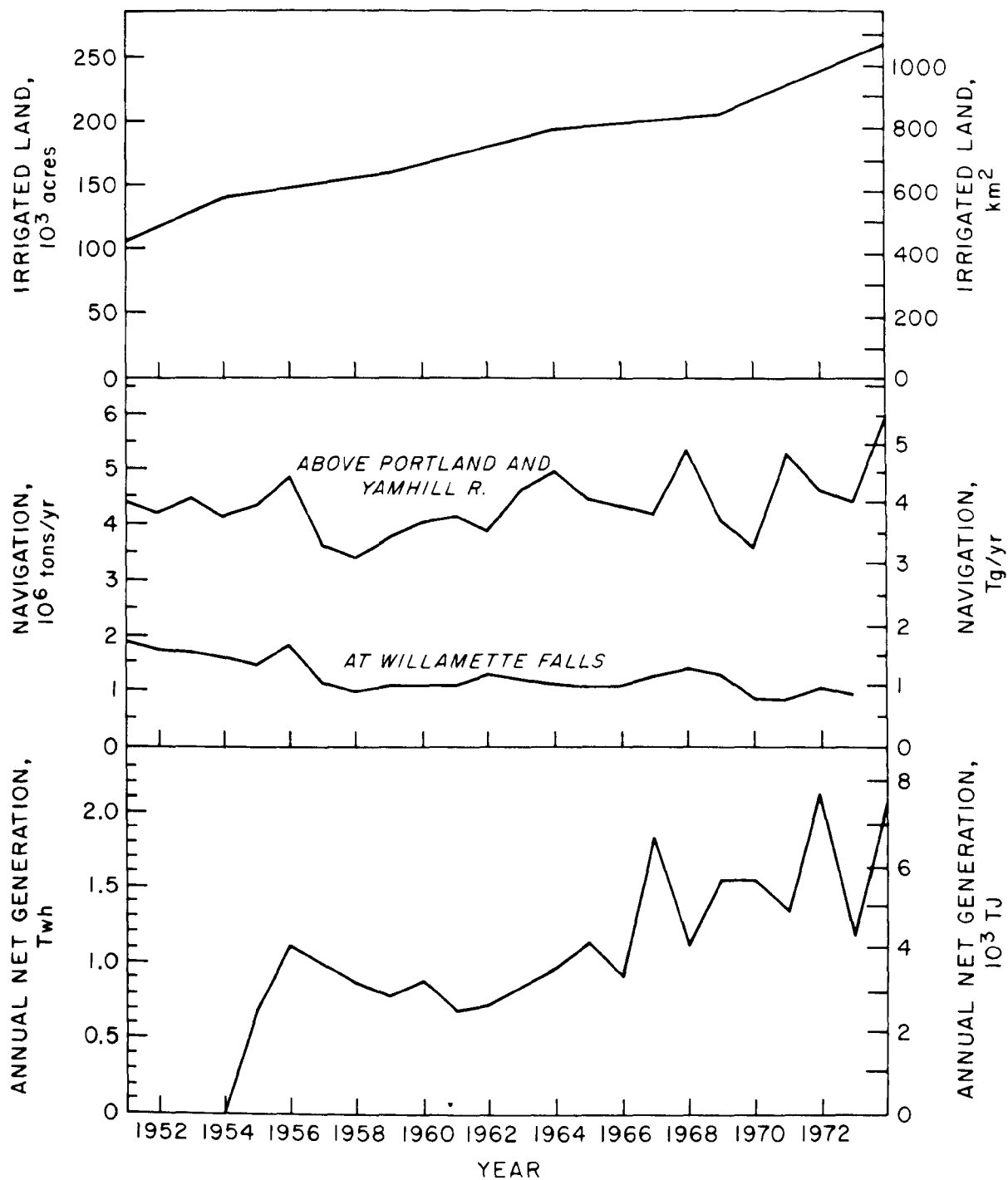
Figure 8. Willamette (a) irrigation, (b) navigation, and (c) electrical generation, 1951-1974 (15, 16, 18, 19).

shown in Figure 8(b). The rafted log portion of this total has fallen from over 50 percent to only 10 percent. Except for a few bulk shipments to and from Salem, the mid-Valley does not depend on substantial river commerce.

Hydroelectric Power

Hydroelectric power is one of the Willamette's products. Of the approximately 8500 TJ generation in 1973, 50 percent was produced by five multipurpose Corps projects on the upper Willamette tributaries. Most of the remainder was developed from Portland General Electric dams on the Clackamas. This utility also operates one small (415 TJ) run-of-river generator at Willamette Falls. The Eugene Water and Electric Board draws approximately 1000 TJ from the high McKenzie (3, 20). Figure 8(c) illustrates the development of Corps' hydroelectric facilities.

Flood Protection

All Willamette Basin projects by the Corps provide flood mitigation. Approximately 70 percent of the combined Corps reservoir storage shown in Figure 9(a) is designated for flood control. Reservoir construction costs alloted to flood control ranges from 32 to 70 percent (21). As seen in Figure 9(b), this investment has been quickly returned. By 1974 when 50 percent of the Basin's flood storage was less than 14 years old, the total reduction in flood damages exceeded 125 percent of the entire reservoir expenses (18, 22). Approximately 70 percent of the return was incurred with the 100-year flood of 1964. Had this flood not occurred, flood control investment would have been returned at an approximate 6 percent rate.

Recreation

Throughout the Willamette watershed, hiking and camping sites are proximate to water. Fishing, boating, and swimming locations are abundant and scenic motor routes follow waterways. During the peak summer months, 175 000 persons per day make use of developed recreational sites (23). This demand is expected to grow at an annual rate of nearly 4 percent. Twenty percent of the visitor days occur at Corps' reservoirs, as indicated in Figure 9(c). Typically, 75 percent of these visitors travel no more than 80 km to the reservoirs. More than 50 percent are from less than 40 km (24). Reservoir sites are more favored by day vacationers, whereas remote fishing streams appeal to the overnighters. What perhaps differentiates the Willamette from many other basins is that recreation is enjoyed not only in protected upstream reaches, but over the entire main stem.

Waste Disposal

The Willamette is extensively employed to assimilate municipal and industrial wastewater discharges. Oregon's Department of Environmental Quality (DEQ) monitors aquatic waste discharges, relates such discharge to water quality, establishes discharge limits to protect and enhance that quality, and enforces those determinations.
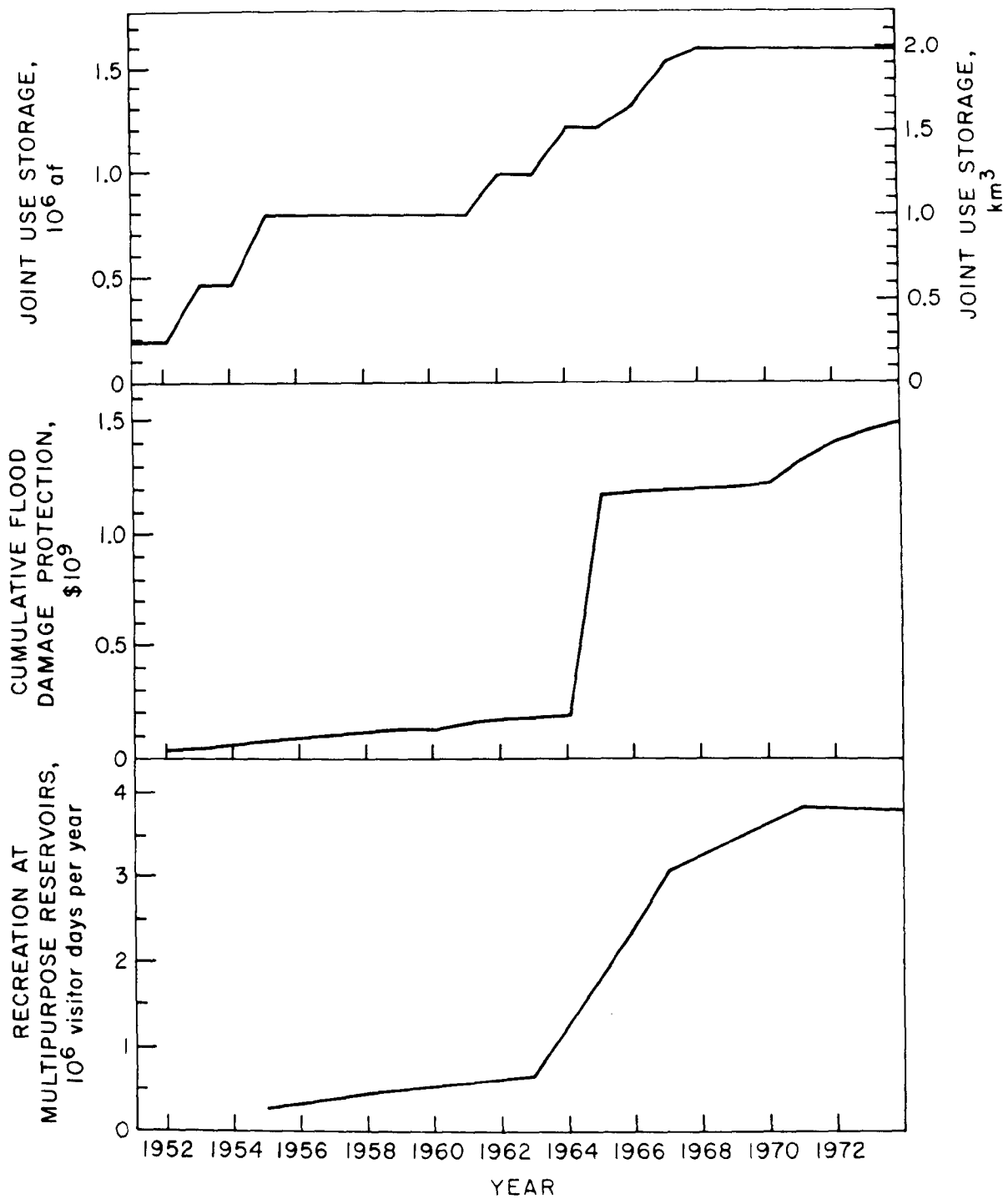
Figure 9. Willamette (a) joint use storage, (b) flood damage protection, and (c) reservoir recreation, 1951-1974 (18, 23).

Major wastewater dischargers can be seen in Table 3 and Figure 10. Figure 11(a) traces the development of municipal wastewater treatment on a population basis. Effective pollution control on the Willamette itself has been more rapid than Figure 10 indicates; the primary discharge continuing through the late 1960's was Portland's wastewater that was released to the Columbia. In Figure 11(b), the river response in August dissolved oxygen is shown. Improvement is due to both wastewater treatment and dilution by flow augmentation from reservoirs. Summer discharges flowing into the Willamette River are listed in greater detail in Appendix A.

Table 4 summarizes discharges of biochemical oxygen demand (BOD), total Kjeldahl nitrogen, and orthophosphate into the Willamette from municipal, industrial, unknown, and nonpoint sources. The "unknown" classification indicates pollutant loadings found by mass balance in the river's main stem, but not identified with known inflows. The "nonpoint" designation is loosely employed; pollutant discharges from tributaries minus residuals of up-tributary point inputs are lumped into this category. Although nearly 30 percent of the Basin is in agriculture, irrigation is limited to light application by sprinkler systems. Scattered animal feedlots and poultry farms are not believed to contribute significant pollutant loadings to streams during the summer. Extensive clearcut logging activity (particularly in the Cascade Range) increases the annual loading of sediments and organic material, some of which may affect summer chemical and biological conditions. Other major sources of nonpoint source pollution, including construction, highways, and urban runoff, contribute pollutant loads primarily during rainy high flow periods.

Historically, benthal oxygen demand has been identified as a major contributor to a recurring, summertime "oxygen dip" noted in the Portland Harbor (1, 28). These benthal deposits were primarily attributed to two sources: (1) overflows of raw sewage from Portland's combined sewer system, and (2) suspended matter, wood, and pulp fibers discharged from upstream pulp and paper industries and municipalities. By the early 1970's, however, the combined sewer overflows had been largely rerouted to a municipal sewage treatment plant on the Columbia River except during winter storm periods. In addition, secondary treatment by the pulp and paper industries and municipalities has drastically reduced their discharges of oxygen-demanding wood fibers and suspended solids. The U. S. Geological Survey (USGS) estimated that the only significant oxygen demanding deposits in 1973 were restricted to the reach below river kilometer (Rkm) 21. This demand was thought to be 18 000 kg/day in the reach Rkm 11-21. The demand was apparently responsible for a major part of the approximate 10 percent decrease in DO levels below Rkm 21 during 1973-1974 low-flow conditions (29). This benthic oxygen demand in the Portland Harbor was proportioned as follows:

    (1) 25 to 33 percent due to natural benthal sediments,
    (2) 25 to 33 percent due to algal respiration, and
    (3) 25 to 50 percent due to an unknown combination of raw
         sewage overflows, ship discharges, navigation dredging,
         riverbed gravel mining, and resuspension of benthal
         materials by tidal currents and prop wash (30).

26

TABLE 3. PRINCIPAL WILLAMETTE BASIN MUNICIPAL AND INDUSTRIAL
WASTEWATER TREATMENT FACILITIES IN 1973 (10)

Municipal facilities	Industrial facilities
1. Salem	A. Wah Chang, Albany
2. Eugene	B. Rhodia, Portland
3. Corvallis	C. Pennwalt, Portland
4. Springfield	D. Evans Products, Corvallis
5. Albany	E. Boise-Cascade, Salem
6. Portland - Tryon Creek	F. Publishers Paper, Oregon City
7. Fanno Creek	G. Publishers Paper, Newberg
8. Oregon City	H. Crown Zellerbach, Lebanon
9. Beaverton	I. Weyerhaeuser, Springfield
10. McMinnville	J. Western Kraft, Albany
11. Oak Lodge	K. Crown Zellerbach, West Linn
12. Milwaukie	L. American Can, Halsey
13. Metzger	M. Oregon Metallurgical, Albany
14. Aloha	N. General Foods, Woodburn
15. Sunset	O. Tektronix, Beaverton

TABLE 4. ESTIMATED LOADING OF P, N, AND BOD TO THE
WILLAMETTE RIVER, AUGUST 1973 (7, 9, 10)

Source	Orthophosphate as P		Kjeldahl N as N		BOD_5	
	kg/d	percent	kg/d	percent	kg/d	percent
Municipal effluents	1 300	66	5 700	25	12 200	25
Industrial effluents	300	14	10 300	45	19 900	41
Unknown*			5 900	26		
Nonpoint Source	400	20	900	4	16 900	34
TOTAL	2 000	100	22 800	100	49 000	100

*See Section VI for discussion

27
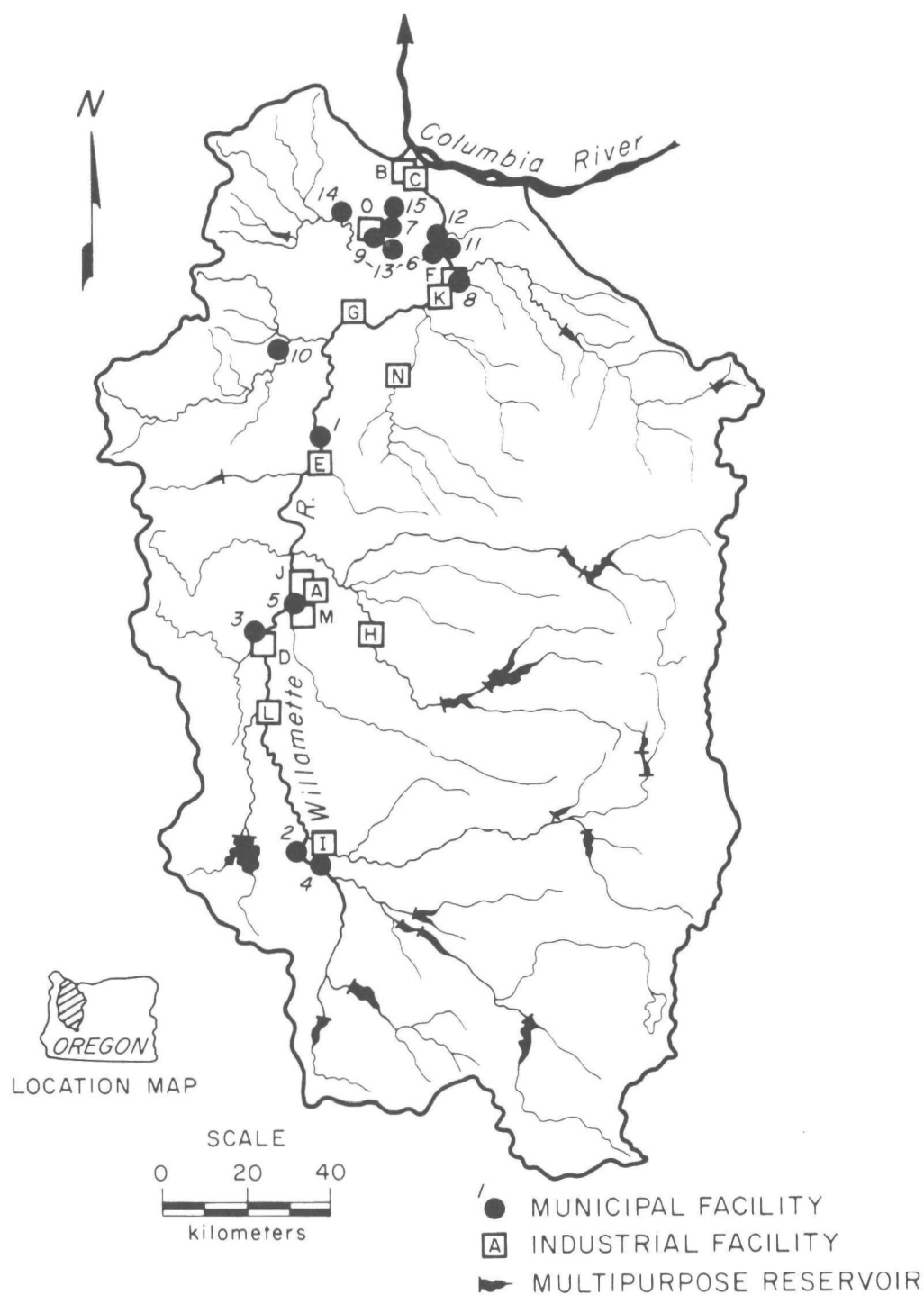
Figure 10. Principal Willamette Basin municipal and industrial wastewater treatment facilities (see Table 3 for key).
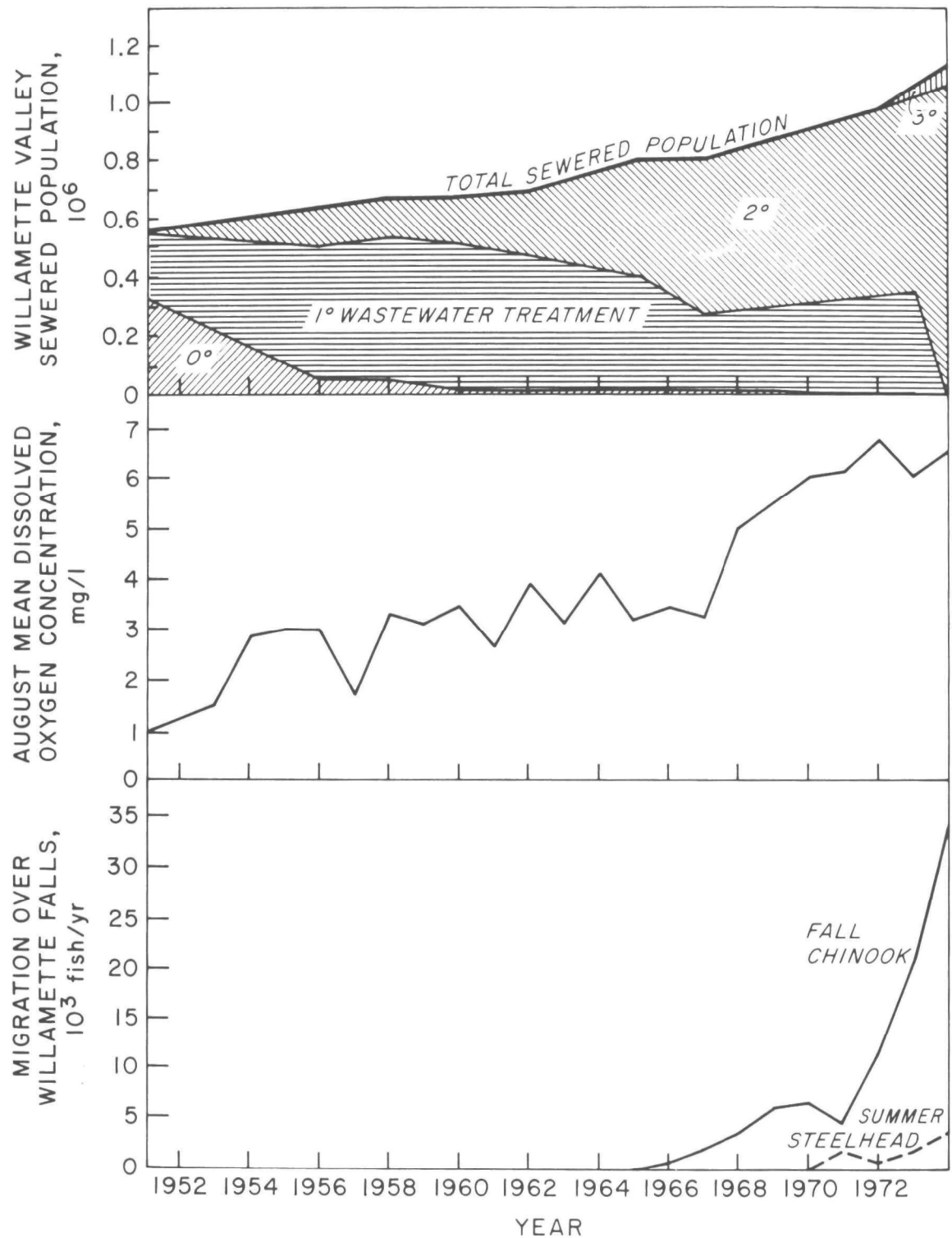
Figure 11. Willamette (a) sewered population, (b) dissolved oxygen, and (c) fish migration, 1951-1974 (3, 25, 26, 27).

Fish and Wildlife

The return to the Willamette of chinook salmon in the fall of 1973, illustrated in Figure 11(c), marked a victory for the river. Oregonians lined the banks to see a reward of pollution abatement. The preservation of fisheries and wildlife in a multiuse river was shown to be achievable.

The Basin contains four National Wilderness Areas and seven Federal Research Natural Areas. The Basin is home for approximately 70 species of mammals, including the Roosevelt elk, gray and red fox, black bear, mule and blacktailed deer, mountain lion, mountain beaver, raccoon, ermine, weasel, mink, and river otter. Over 30 reptile and amphibian species are found. More than 40 species of fish inhabit the Willamette and its tributaries. Coho, sockeye, and chinook salmon; cutthroat, rainbow, brown, and brook trout; and largemouth bass are fished. Sturgeon, carp, dace, and sculpin are present. Ornothologists have identified over 150 breeding birds. Geese, great blue heron, teal, kingfishers, mallards, merganser, and sandpipers are seen along waterways (31).

Pollution Control Expenditures

The return of water quality illustrated in Figure 11 was purchased, not freely gained. Figure 12 indicates the capital investments for (a) wastewater treatment plants, interceptors, outfalls, and lift stations, (b) industrial pollutant removal, and (c) multipurpose reservoirs used for instream pollutant dilution.

Capital expenses for Valley treatment plants as of August 1973 were $67.2 million (all costs in 1973 dollars). At the end of 1974 the sum was $143.3 million. Of this total, $58.6 million was spent after August 1973, $7.7 million was invested in plants discharging out of the Basin, $3.9 million was spent for plants not discharging to streams in August, and $5.8 million was invested in plants since abandoned.

Construction records indicate that through 1973, over $87 million had been invested in Basin sewer interceptors, wastewater outfalls, and sewage lift stations. Approximately 60 percent of this sum was used to remove Portland discharges from the Willamette to the Columbia. For industrial wastewater cleanup in this same period, $72 million was spent. Construction value of the Corps' multipurpose reservoirs exceeded $1 billion (3, 18, 22, 25, 26, 27).

Reservoir Authorization for Water Quality Control

A review of Congressional authorization for reservoir construction provides background for estimation of reservoir cost for pollution control. Water pollution control is not an authorized primary purpose for any Corps' Willamette reservoir. The Willamette River Basin Flood Control Act of 1938, the original authorization for Willamette reservoir construction, followed the heralded Columbia and TVA patterns for development: regional economic growth stemming from flood control, power, navigation, and irrigation. Congress laid out a plan of reservoir construction on Willamette tributaries for those ends.
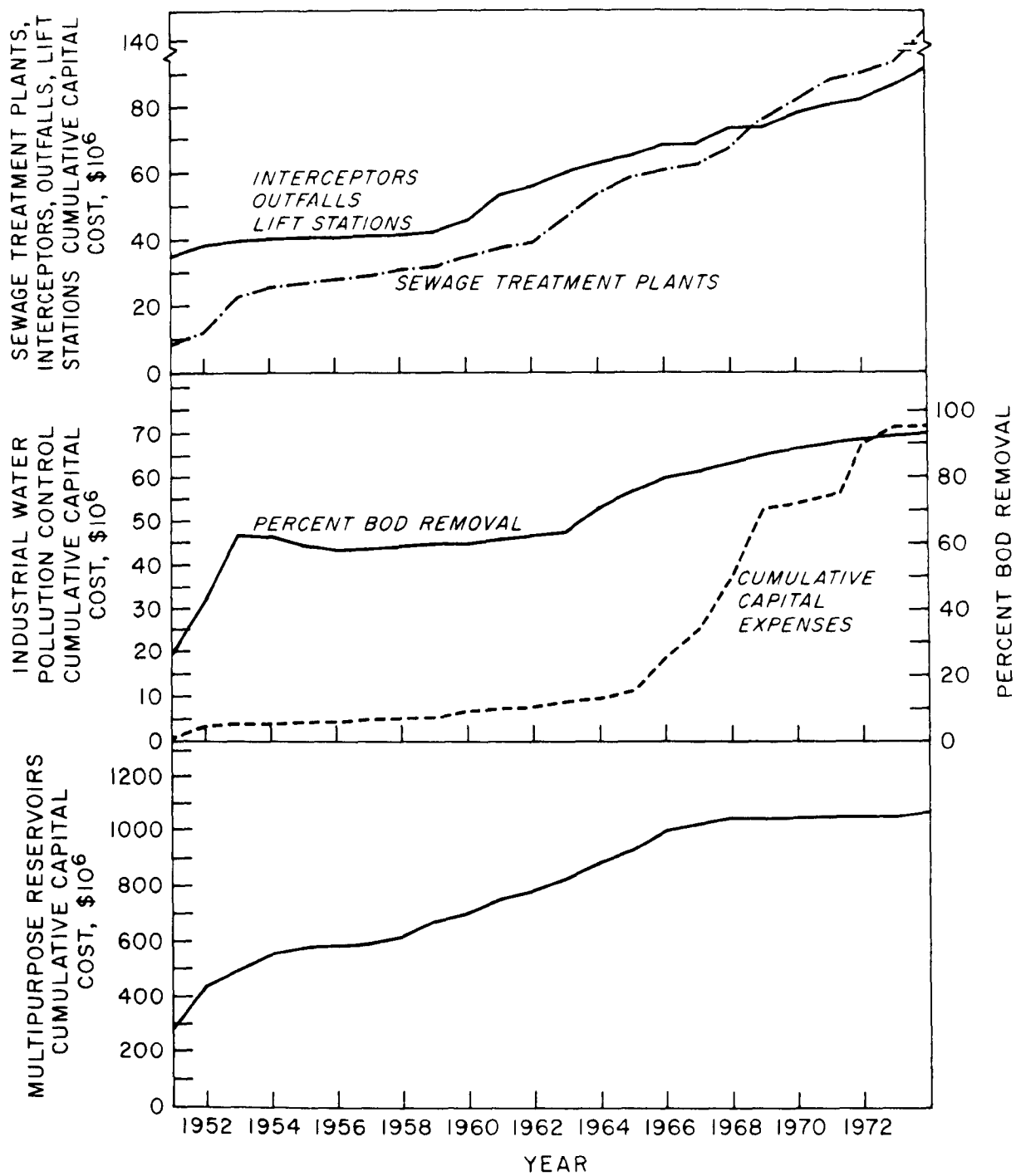
Figure 12. Willamette (a) municipal and (b) industrial wastewater treatment and (c) reservoir costs (18, 22, 25, 26, 27).

By the 1950's and 60's when final reservoir plans were drawn and approved, it was realized that the projects would have impacts outside of those several purposes. Recreation, fish and wildlife enhancement, municipal and industrial water supply for downstream users, and water quality control were seen as additional project benefits. The Flood Control Acts of 1944, 1946, and 1954 designated recreation as an authorized specific use, thus allowing it to be included in the comprehensive evaluation of reservoir economics (32, 33).

Within the limits of the 1938 Act, a broader interpretation was given to project purposes of low flow augmentation in the 1950's. In addition to navigation and irrigation benefits during the summer season, a water quality control benefit (then seen as approximately 3 percent of total benefits) was included in benefit-cost calculations for the project. The anticipated water quality benefits reflected pollution control cost reductions. Significantly, pollutant dischargers did not realize such savings in waste treatment expenses. Rather, the dischargers incurred substantial cost in upgrading their effluents to secondary quality.

The Federal Water Pollution Control Act Amendments of 1961 (PL 87-88) provided for water quality control to be a recommended project function for reservoirs being planned and those in initial stages of construction. The Willamette Basin Comprehensive Study investigated and recommended such addition of purpose for Federal reservoirs. However, by the time of this determination, the Corps had successfully justified its reservoir plans independently of water quality improvement (21).

The Corps' conservative cost accounting proved to have foresight. The Federal Water Pollution Control Act of 1972 (PL 92-500) again called for streamflow regulation policies to be determined with water quality control in project economic design. The Act, however, also specified that storage and releases from reservoirs could not be justified as a substitute for adequate at-source waste treatment, "adequate" being defined as the best practicable or available technical level. Thus, water pollution control benefits could only be claimed for Corps' projects that improved water already receiving only the highest treated discharges. Since such "adequate" treatment capacity approaches complete pollutant removal, the Corps could only count pollution control credit for improving water quality above its natural, unpolluted level. In effect, water quality from flow augmentation ("solution by dilution") are not presently authorized benefits for reservoir construction (34). Though Federal reservoirs do contribute to Willamette water quality maintenance, the DEQ can neither rely on this strategy nor can the Corps claim economic benefits for this environmental service.

SUMMARY

The Willamette Basin's physiographic setting gives rise to its varied water resources. The State Water Policy Review Board summarizes:

1. The total surface water yield in the basin is sufficient to meet all foreseeable needs,
2. The temporal distribution of runoff results in water shortages in some areas,

3. Low flow augmentation can be obtained through storage of winter flows, and
4. Augmented flow is required to protect several seasonal water resource benefits (35).

Water resource employment is varied, but to a large extent complementary. Reservoirs are maintained at high levels for much of the recreational season. Reservoir releases in preparation for the winter flood season coincide with downstream needs for water supply and water quality protection. To the present, consumptive use of the Willamette, principally for irrigation, has not greatly competed with instream water requirements.

Mankind's employment of the Willamette River has increased over the years. To both make use of the river resources and maintain water quality, substantial investment has been made for water pollution control. A portion of this investment has gone for wastewater collection, treatment, and diversion. Another portion of these costs has purchased augmented flow, an unauthorized benefit from multipurpose reservoirs.

SECTION V

POLICIES

PERSPECTIVES FOR RESOURCE MANAGEMENT

Governmental policies can be described as high-level overall plans that embrace general goals and acceptable procedures. From those policies, resource management issues emerge which involve environment, economics, and energetics. Resource management reflects environmental policies, plans, and procedures for protecting natural resources. Resource management is a major part of economic policies that seek to increase the material enjoyment of life. Utilization of natural resources often reflects energy policies that direct work allocation. Any of the three policies can, in fact, be conceptualized as incorporating the remaining two. Although man could unify his resource management policies under one perspective, this is generally not done. Rather, issues are examined from several viewpoints, each with somewhat independent policies. The selection of a particular solution seems to depend on the compatibility to the most or highest-order policies. This determination is typically social, not technical.

When policies are well defined, ranked, and accepted, issues of resource utilization can be easily resolved. However, if the policy perspectives are not well defined or generally accepted, resource decisions become difficult.

This section explores three policies pertinent to Willamette pollution control. Environmental, economic, and energy policies are introduced so that analytical results presented later in this report may be compared to public goals. If policy and prediction seem to substantially differ, then recommendation to make policies more realistic can be made.

ENVIRONMENTAL PERSPECTIVE

The Water Quality Management Plan

The Oregon Department of Environmental Quality's (DEQ) Water Quality Management Plan reflects the State's commitment to pollution control. The plan, adopted December, 1976 in compliance with Federal regulation PL 92-500 furthers Oregon's tradition of being a frontrunner in water pollution abatement.

> "Whereas 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

34

other legitimate beneficial uses of the water, whereas the problem of water pollution in this State is closely related to the problem of water pollution in adjoining states; it is hereby declared to be the public policy of this State:

(1) To conserve the waters of the State;

(2) To 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;

(3) To provide that no waste shall 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;

(4) To provide for the prevention, abatement and control of new or existing water pollution; and

(5) To cooperate with other agencies of the State, agencies of other states, and Federal Government in carrying out these objectives." (36)

The Water Quality Management Plan seeks to continue a determined and cooperative pollution reduction policy by proven means of waste treatment. Implementation of the plan calls for more advanced wastewater treatment to reduce carbonaceous BOD, suspended solids, and coliforms. The plan recognizes problems of nonpoint source pollution and riverbed benthic materials as future, not immediate, targets for control. To limit industrial wastewater effluents the plan extends Oregon's pragmatic approach of seeking reasonable industrial cooperation in lieu of governmental litigation. The Water Quality Management Plan is a substantial conventional sanitary engineering endeavor.

Goals of the Water Quality Management Plan are transformed into tactical regulations by the DEQ. Relevant to the environmental model developed in the next section are the DEQ's standards. In the tidal reach below Willamette Falls the minimum permissible dissolved oxygen (DO) is 5 mg/1. Above the Falls to Newberg the level is 6 mg/1. From Newberg to Salem the standard is set at 7 mg/1 above Salem, 8 mg/1.

Environmental Policy

The generalized State environmental policy is illustrated by the Water Quality Management Plan. State goals call for (1) the prohibition of further environmental degradation within the State, and (2) the improvement of natural resource quality where practicable. Acceptable procedures for these ends include (3) pragmatic cooperation between Federal, State, local, and industrial officials, and (4) the maintenance of regulations and enforcement capacity directed toward environmental quality.

ECONOMIC PERSPECTIVE

Oregon's economic policies center on the general goal of improving per capita income and reducing unemployment (37). Economic policies are perhaps easier to identify in action than in legislation, as activity speaks for itself. Several indices of economic behavior are discussed below.

Indices of Resource Utilization

Ten percent of American softwood timber stands in the Willamette Basin. Of the Basin timber harvest, 90 percent is sent to national and world markets (11). The pulp, paper, and particle board industry steadily converts sawmill wastes (once incinerated) into marketable goods. Statewide, the value of the forest products industry's payroll exceeds $1 billion. Forty-two percent of the State's entire population receives income derived directly or indirectly from the forest industry (38). The Basin is a foremost producer of grass seed, hops, and mint. Nearly half of the State's $1 billion annual farm and ranch gross sales comes from the Valley (39). One out of five workers in the Basin is employed in renewable resource harvest and processing (11).

Oregon sportsmen devote more than 2 million person-days yearly to hunting and fishing. Sportsmen pay license fees (approaching $10 million annually) and help sustain a year-around tourist industry (40). In short, the economy of the Willamette Basin is significantly derived from the harvest of renewable natural resources.

The aesthetics of the natural environment and the prosperity derived from resource harvests have drawn to the Valley small non-resource based firms. A large part of Valley industry produces commodities of high value and little bulk, e.g. electronic equipment or refined rare metals. Such industry is actively sought by the State. Should living conditions, local taxes, or State regulation become unacceptable, these industries possibly would leave the area.

Indices of Income

Mean personal income in the Willamette Basin is greater than that of the rest of the State ($5520 versus $4770 in 1974), the difference in large part due to the Valley's urban employment. In the past 25 years, the Basin's median family income has improved relative to that of the State. In this period, the majority of Willamette Valley counties dropped below the State mean percentage of families living in poverty. Income is more evenly distributed in the Valley than in the State as a whole. By any of the four measures (mean income, median income, poverty percentage, and income distribution), the Valley has a reasonably healthy income (41).

Indices of Population

Willamette Valley counties have experienced a 1.74 annual percent growth in population over the past 15 years. Although population stabilization is now generally assumed to be a necessary condition for preserving the Valley's quality of life, in the next decade the rate is not anticipated to greatly

change (21, 42). Somewhat less than half the population growth in Oregon is attributable to immigration (43).

Economic Policy

The masthead of the State Economic Development Commission once heralded "Oregon, the Growth State". Its newsletter was "Grow with Oregon". However, environmental issues of the 60's have brought reevaluation. "Grow with Oregon" was relabeled "Oregon Quality" in 1970. Perhaps the subsequent title "Oregon Progress" reflects a slight rebound, a middle way. An economic policy for Oregon has been established:

"(1) There exists in the State a great and growing need for balanced economic and community development to provide and maintain orderly economic growth and the preservation and enhancement of all facets of Oregon's environment;

(2) Only properly planned and coordinated growth and development can maintain and improve the total environment by broadening the tax base. . .;

(3) . . . Balanced development opportunities must be made available to rural areas to bring about the geographical distribution of business and industry necessary to a healthy economy and environment for all Oregonians;

(4) Assistance and encouragement of balanced industrial, commercial and community development is an important function of the State. . .;

(5) The availability of this assistance and encouragement is an important inducement to industrial and commercial enterprises to locate, remain and relocate in those portions of the State which will contribute most of the environment and economy of Oregon. . .; and

(6) Development of new and expanded overseas markets is an area of great potential for furthering balanced economic growth. . . thereby contributing to economic diversification." (44)

Redundant in the policy is the State economic goal: to sustain economic growth. There is little willingness to forego the benefits of resource harvests, the healthy Basin income pattern, or the population growth complementary to traditional economic development. There is general willingness to invest dollars in pollution management to avert the penalties associated with a polluted region.

ENERGY PERSPECTIVE

Energy is required for protection of multipurpose environments, yet energy production often degrades that environment. Energy consumption is required to fuel an economy, but energy depletion may curtail much economic ac-

tivity. This section outlines several aspects of Willamette Basin energy use, illustrating problems confronting energy policy of the 1970's.

Energy Consumption

Records of energy usage in the Willamette Valley incorporate electrical, natural gas, and petroleum product data. Whereas such accounting does not describe the area's total energy budget, the statistics do reveal significant and manageable aspects of the region's energy base. Unless indicated otherwise, the trends and generalities of the State are substantially the same for the Willamette Valley.

Energy consumption in Oregon regularly increased until the oil embargo of 1973 (Figure 13). Oregon's energy consumption growth rate has historically been more variable than that of the nation. Overall, Oregon has experienced a higher than national rate of energy growth (4.7 versus 3.3 percent average growth rate of total energy consumption and 2.8 versus 2.2 percent average annual per capita increase, 1962-1974) (45, 46).

Oregon's petroleum and natural gas requirements are met by imports. Thirty-three public and private utilities in 1974 supplied the State's electrical needs. These utilities are members of the Northwest Power Pool, a program of unified regional power production. Eighty-five percent of the Pool's production comes from dams. Of this, most comes from Bonneville Power Administration's Columbia reservoirs. Approximately 10 percent of the Willamette electrical consumption is hydraulically produced within the Basin (48).

Power is traded with the Pacific Southwest on an annual cycle. High Columbia summer flow generates electricity in excess of northwestern immediate demand. The surplus is transmitted via high voltage lines to California and Arizona. Electricity is returned during the winter when the southwest's cooling demands are reduced and the northwest's heating needs are greatest. Such transshipment is estimated to cost 25 percent as much as otherwise-required regional power plants for peak seasonal demands (47). The Willamette Valley, then, regularly consumes electricity generated throughout the western United States.

Energy Forecasts

Energy use forecasts vary. Private electrical power suppliers project nearly a complete continuance of the 6.3 percent growth rate from 1962-74. State officials, placing more credence in demand elasticity, expect 3.3 percent. In either case, no plateau in energy demand is foreseen. Increased electrical production will be derived from three thermal facilities (one coal and two nuclear) in eastern Oregon. The residential sector will demand most new electrical output.

Petroleum consumption is forecast to accelerate at a 4.5 percent rate. This exceeds the growth rate of the past decade. The clear assumption is that the oil will yet be available. Natural gas supply is predicted to decrease, jump, and decrease in the next 20 years. Industrial gas delivery will be cut back.
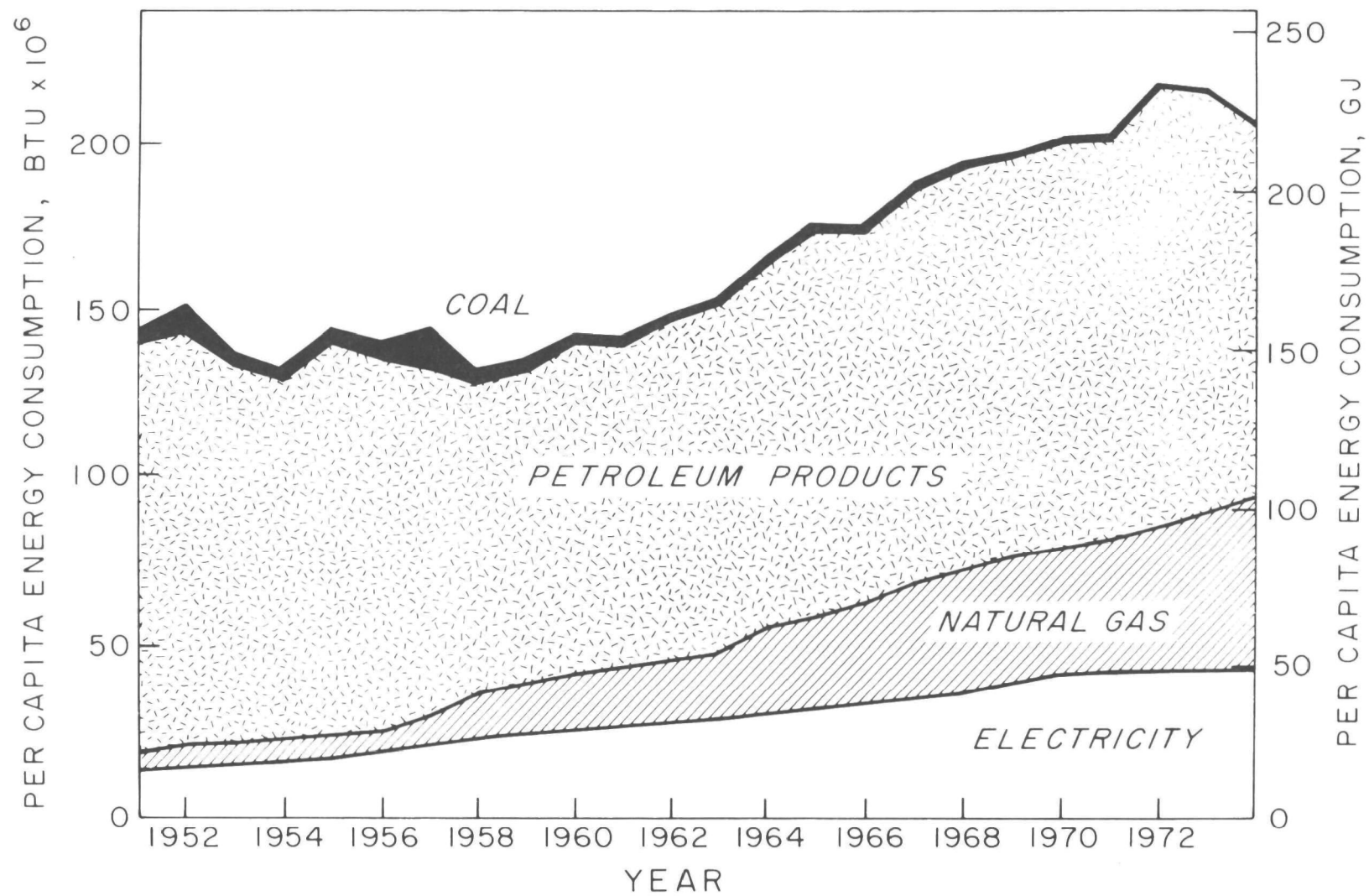
Figure 13. Oregon per capita energy consumption, 1951-1974 (45, 46).

Overall, higher consumer incomes are anticipated to reverse the temporary downward energy trend begun in 1973. The subsequent increases in energy demand will eventually slow under the pressures of higher prices, reduced population growth, decelerating effective per capita income, and diminishing expansion of industrial production (45).

Energy Policy

Given Oregon's dependence on imported energy, the decreasing world energy stocks and Oregon's anticipated growth in energy requirements, the energy policy of the State centers on two concepts: energy conservation for essential purposes and local development of renewable energy sources (45, 49). The State energy policy is briefly as follows.

"(1)   That development and use of a diverse array of permanently sustainable energy resources be encourage utilizing to the highest degree possible the private sector of our free enterprise system.

(2)   That through State government example and other effective communications, energy conservation and elimination of wasteful and uneconomical uses of energy and material be promoted.

(3)   That the basic human needs of every citizen, present and future, shall be given priority in the allocation of energy resources, commensurate with perpetuation of a free and productive economy with special attention to the preservation and enhancement of environmental quality.

(4)   That all State agencies, when making monetary decisions, take into consideration cost factors, including but not limited to energy resource depletion and environmental costs." (50)

Oregon's energy policy is essentially one of fossil fuel and electricity (high grade energy) management. Oregon's energy policy is directed toward both altered patterns of energy consumption and production. The overall goal is that of insuring an adequate long-term high-grade energy supply. Generalized policy calls for (1) the conservation of fossil fuel reserves for essential purposes and (2) the development of local, renewable energy producing capacity. Records and projections indicate (1) is not taking place. Technology of the foreseeable future is not apt to bring about (2). Unlike environmental and economic objectives, areas in which Oregon can turn to experience, energy policy may reflect desires not reconciled with all the facts.

AN ALTERNATIVE PERSPECTIVE

Environmental, economic, and energy policy might be unified if issues were seen in a broader framework. The many aspects of water pollution control strategy might be seen together, yielding coordinated resource management. Some overlapping of environmental, economic, and energy terms in policy statements does indicate that some perspective unification is coming about, but it is more semantic than actual.

A more methodological approach to comprehensive policy stems from the field of ecology. This perspective, popularized by H. T. Odum, calls for reduction of all activity to an energy structure (51). Such energy analysis requires both quantity and quality appraisal. Activity has quantity as calorie transfer and quality as its ability to bring about work. Energy used to regulate the flow of other energy is deemed to be of higher quality than the regulated energy. In so regulating, it can cause more work to be done than would occur otherwise. Odum's proposals for many of today's social and ecological problems call for strategic interaction of high and low quality energies. A calorie of electricity spent for household heating is to Odum ill-employed. The electrical calorie used to facilitate primary production of wood, say, might be better invested. Odum is concerned with energy's effect upon the world system, not just fuel for man's spending.

A realistic policy for the environment, economy, or fuel supply must conform to a viable total energy structure. Odum's approach to public policy formulation calls for the determination of the many fold energy pathways that sustain man's way of life. High quality energy used to pump more energy into the system is identified. If an inflow of energy is desired, the proper policy must be one in which the regulating energy flow is maintained.

In such light, the Willamette Valley might be viewed. Figure 14 represents an initial and partial conceptualization of the Valley's energy basis. Several inflows of energy enter the Valley. Two of them, solar and precipitation, are flow resources from essentially a constant sun, thus "renewable". The remaining two inputs, fuels and raw materials, are derived outside the Basin, in part from renewable sources, but mostly through depletion of national and international nonrenewable energy reserves. In-Basin renewable energy supply is shown as forest and crops, quantified by caloric value. Within the Basin, hydroelectric power is generated from precipitation runoff, estimated to be the potential energy of flow channelized in streams. Energy flows attributed to each of the above are indicated as caloric flux uncorrected for quality. Odum suggests fossil fuel equivalent units for all flows. Such correction for quality would yield 16×10^{12} Cal for sunlight, 5×10^{12} for primary production, 5×10^{12} and 10×10^{12} for crop and timber harvest, and 51×10^{12} for precipitation. The hydroelectric power produced in the region would be valued at 8×10^{12} fossil fuel equivalent Cal and the electricity imported, 56×10^{12}. All other values shown are expressed directly as fossil fuel equivalent energy units. Figure 14 may be modified in this manner to standard units. This modification is here left to the reader's discretion and to reader's agreement with Odum's method. Calculation of values shown is given in Appendix J.

An Odum-based evaluation of pollution control costs might extend to estimates of primary production lost with reservoir innundation or nutrient (high quality energy) return to agricultural land. In this investigation, such issues are not pursued. They are not unimportant topics, but rather questions presently outside the domain of government energy policy and thus beyond the objectives of this study.

The alternative policy perspective proposed is thus one schematized in an Odum manner, but not extended to his comprehensive "total" energy picture.
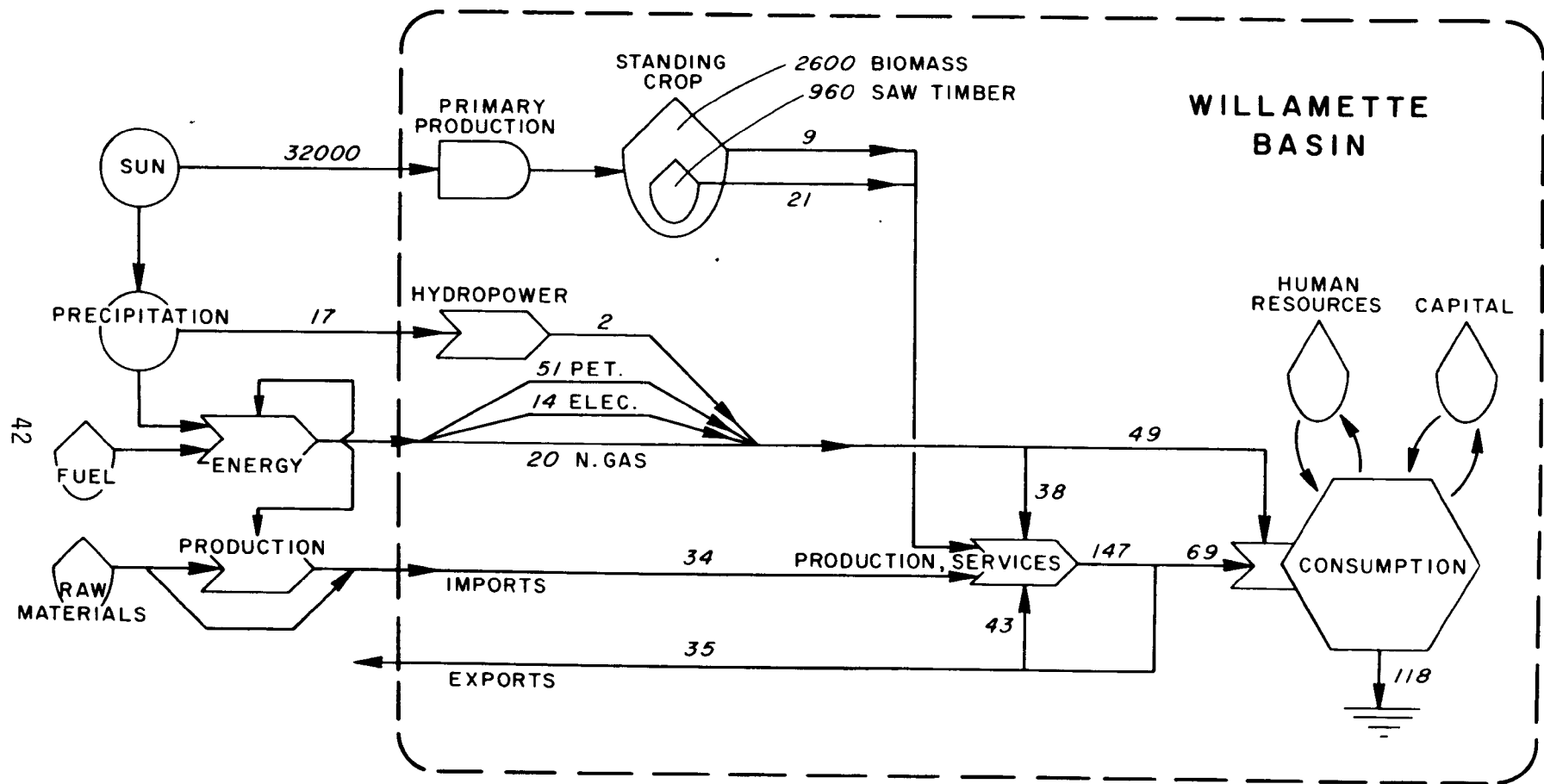
Figure 14. Willamette Basin energy flows, 1973 in 10^{12} Cal per year.

The alternative policy perspective brings together aspects of pollution control, economic, and energy policies in a manner that would lead to coordination among those policies. Should a total energy perspective be pursued as planning evolves, the data of Figure 14 provide a framework for the economic portion of that effort.

Energy as imported power, materials, and capital is purchased with outputs of Valley economic production. Much imported energy, however, is not paid for with produce export. Because the market price for power has traditionally been much lower than the marginal value derived from that power, the Willamette Basin, like many affluent regions, has grown accustomed to development afforded by this net energy subsidy. The Valley's economic sectors of production and service transform this subsidy into goods and services enjoyed by Valley residents.

Though Figure 14 reflects only order-of-magnitude estimation, several conclusions can be drawn:

1. The Basin's economy is principally energetically maintained from imported nonrenewable sources.

2. The Basin benefits from an advantageous energy pricing situation. Far less than half the value derived from imported energy is exported in repayment.

3. The Valley cannot maintain current economic levels fueled by the Basin's wood or hydroelectric power.

4. The consistency of energy subsidies control the Basin's long-range economy, not industrial capacity within the Valley. A primary concern of Basin policy must be that of maintaining the external energy stock from which to draw. The consequences of Valley activity must be seen in a larger scale than that of local expenditure for power. The net national, and potentially international, effects must be anticipated. The policy reduces to a survival strategy within energy-imposed limits.

SUMMARY

Environmental, economic, and energy policies for Oregon are identified. Each has consequences significant to water pollution control. These policies provide perspectives from which the effects of resource management can be weighed. For Willamette water quality control, these policies will be used in Section X as illustrative criteria for management decisions.

The energy perspective of Odum has been used to identify patterns and limits to which workable environmental control must be reconciled. This alternative perspective will likewise be used later in this report to view strategies of water quality control.

SECTION VI

ENVIRONMENTAL MODELING

INTRODUCTION

A model is defined by Weinberg as: an expression of one thing we hope to understand in terms of another that we think we do understand (52). In modeling one seeks to integrate a rational set of concepts that satisfactorily describe a "real" system. Mathematics are commonly employed to provide an internally consistent, rigorous expression of the concepts. Modeling is a subjective enterprise. Models identify not necessarily the problem, but the modeler's notion of the problem. In this section a dissolved oxygen model of a river is discussed and its relationship to the larger issue of Willamette environmental quality is examined.

In environmental issues where a vast number of factors interplay, models frequently succumb to one of two errors. These errors either result from an unfortunate choice of what to model (error in model selection) or an unfortunate decision of how to model (error in model formulation). No matter how well expressed, a model of the wrong environmental attribute will fail to elucidate the behavior of interest. In addition, a model will be of little value if its analytic expression is inappropriate, no matter how carefully the environmental factors to model are chosen.

MODEL SELECTION

Dissolved oxygen (DO) models were among the first analytic expressions of water quality behavior and much is known about this type of model; however, DO models are often abused due to an over-confidence in their applicability. Having learned DO equations from textbooks, engineers too often immediately apply the calculations to any aquatic water quality problem. Other quality parameters may be given little consideration, not because of their lack of importance, but because models for these parameters are less familiar to the engineer. Conversely, DO modeling may be slighted by the engineer for the very reasons that it is older, not sufficiently complex, and less encompassing. The temptation is great to model "everything." Problems arise when an array of complex parameters, not necessarily appropriately modeled, masks the significance of the few parameters basic to understanding environmental conditions.

The Willamette has experienced both these modeling problems. Simple DO models have been applied for general or example results (53, 54, 55). Few model improvements were undertaken after the studies. The value of modeling was, thus, largely limited to immediate problems of interest to the investi-

44

gator, usually an academician. Model extrapolation to the more general audience of planners was largely unsuccessful. The State Sanitary Authority in the 1950's anticipated Willamette water quality conditions primarily by insight, rather than by modeling.

Often present environmental analysis succumbs to the second problem of overencompassment. For example, models too complex for ready appraisal and modification, too reliant on generalities, too ignorant of local conditions, and too inclusive to unnecessary aspects have been applied to the Willamette (56, 57). Results were based on sparse data, inappropriate model structure, and coefficients determined without independent measure. Little confidence is merited for such model output.

Dissolved oxygen appears to be the most suitable parameter for quality modeling of the Willamette River. The reasons are specific to the river, not general to aquatic modeling. Parallel studies have considered other possible indices of pollution: metals, erosion-sedimentation, and nutrients (58, 59, 60). None of these parameters corresponds to the river's ability to sustain a diverse ecosystem better than DO. DO is an integrative parameter of the river environmental system. Natural regulation of river DO includes precipitation patterns, topography, groundcover, and the natural carbon and nitrogen cycles. Man-influenced controls include discharges of carbonaceous and nitrogenous wastes, land use as it affects runoff, and reservoir regulation. Thus, a model of Willamette DO can serve as an encompassing, broad-based expression of river environmental quality.

The rest of this section deals with the adequate expression of a Willamette DO model suited to the objectives of this study.

MODEL FORMULATION

A basic DO model is expressed as a multi-step mass balance. For river study, the channel is conceptually partitioned into reaches, each typified by hydraulic dimensions of width, depth, length, and discharge. Each reach receives inputs of oxygen, water, and oxygen demanding substances from the reach immediately upstream and/or from discharges along its banks. Within any reach, the DO concentration may be reduced by oxygen-demanding degradation of waste materials or increased by atmospheric or other reaeration mechanisms. A DO model can be visualized as a series of conceptual hydraulic reaches, each linked by interreach transport couplings, and each reach having potential oxygen sources and sinks. Boundary conditions are established and coefficients appropriate to internal model mechanisms are determined.

Oxygen sources and sinks meaningful for a Willamette model include biochemical oxygen demand (BOD), both carbonaceous and nitrogenous; immediate oxygen demand (primarily benthic exertion); and atmospheric reaeration. Figure 15 illustrates the basic dissolved oxygen model. Equations 1 through 5 define the expressions in general terms. The model is expressed in detail by the computer routines listed in Appendix B. The atmospheric reaeration term of Equation 1 is documented in Appendix C.
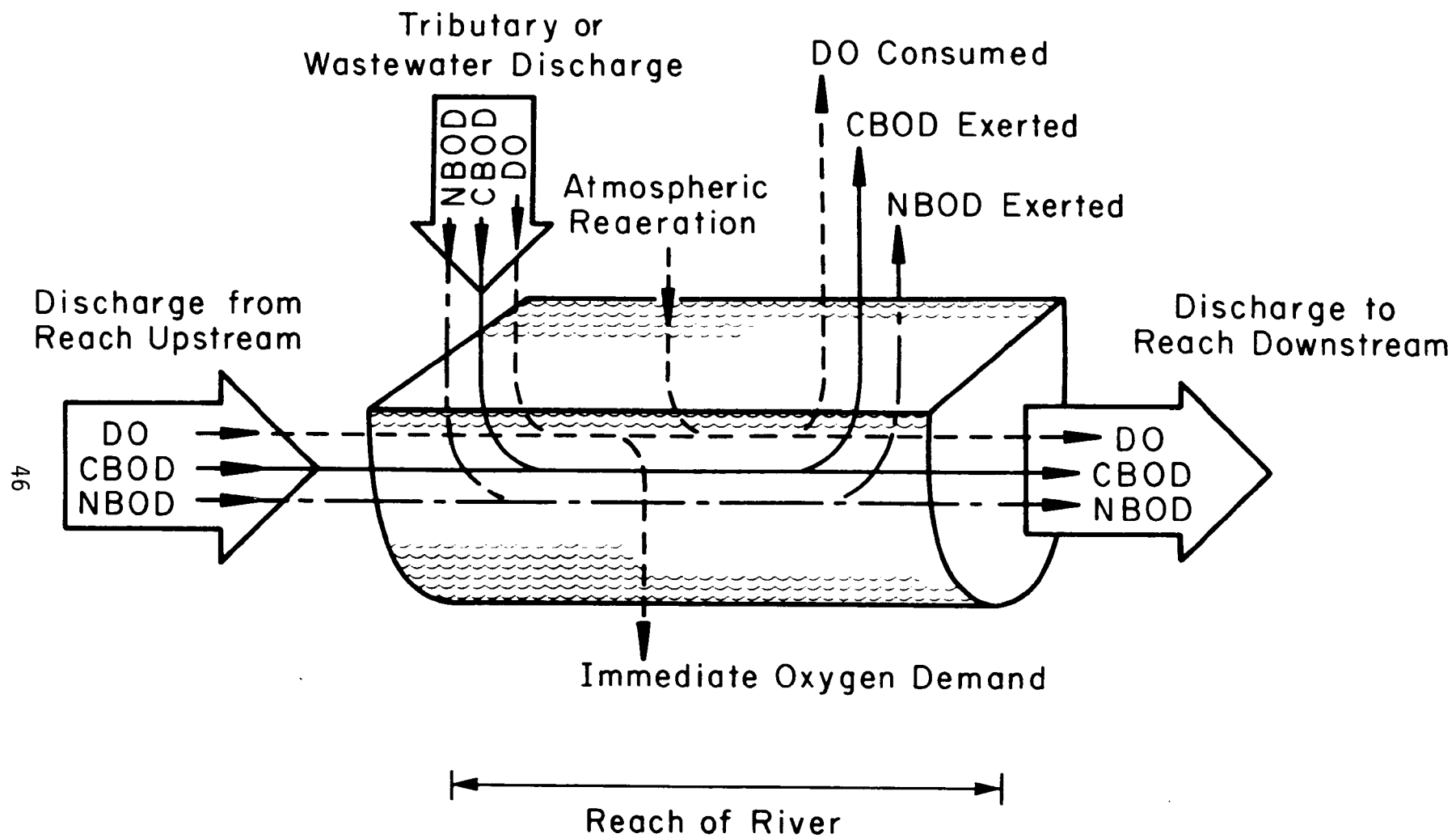
Figure 15. Dissolved oxygen river schematic.

$$
\begin{bmatrix} \text{DO at} \\ \text{bottom} \\ \text{of reach} \end{bmatrix}
=
\begin{bmatrix} \text{DO from} \\ \text{upstream} \\ \text{reach} \end{bmatrix}
+
\begin{bmatrix} \text{DO in} \\ \text{tributary or} \\ \text{wastewater} \end{bmatrix}
-
\begin{bmatrix} \text{Immediate} \\ \text{oxygen} \\ \text{demand} \end{bmatrix}
$$

$$
-
\begin{bmatrix} \text{Carbonaceous} \\ \text{BOD} \\ \text{exerted} \end{bmatrix}
-
\begin{bmatrix} \text{Nitrogenous} \\ \text{BOD} \\ \text{exerted} \end{bmatrix}
+
\begin{bmatrix} \text{Atmospheric} \\ \text{reaeration} \end{bmatrix}
\qquad (1)
$$

$$
\begin{bmatrix} \text{Carbonaceous} \\ \text{BOD at bottom} \\ \text{of reach} \end{bmatrix}
=
\begin{bmatrix} \text{Carbonaceous} \\ \text{BOD from} \\ \text{upstream reach} \end{bmatrix}
+
\begin{bmatrix} \text{Carbonaceous} \\ \text{BOD in tributary} \\ \text{or wastewater} \end{bmatrix}
-
\begin{bmatrix} \text{Carbonaceous} \\ \text{BOD} \\ \text{exerted} \end{bmatrix}
\qquad (2)
$$

$$
\begin{bmatrix} \text{Nitrogenous} \\ \text{BOD at bottom} \\ \text{of reach} \end{bmatrix}
=
\begin{bmatrix} \text{Nitrogenous} \\ \text{BOD from} \\ \text{upstream reach} \end{bmatrix}
+
\begin{bmatrix} \text{Nitrogenous} \\ \text{BOD in tributary} \\ \text{or wastewater} \end{bmatrix}
-
\begin{bmatrix} \text{Nitrogenous} \\ \text{BOD} \\ \text{exerted} \end{bmatrix}
\qquad (3)
$$

$$
\begin{bmatrix} \text{Carconaceous} \\ \text{BOD} \\ \text{exerted} \end{bmatrix}
=
\left\{
\begin{bmatrix} \text{Carbonaceous} \\ \text{BOD from} \\ \text{upstream reach} \end{bmatrix}
+
\begin{bmatrix} \text{Carbonaceous} \\ \text{BOD in tributary} \\ \text{or wastewater} \end{bmatrix}
\right\}
\begin{bmatrix} 1-10^{-K_1 t} \end{bmatrix}
\qquad (4)
$$

$$
\begin{bmatrix} \text{Nitrogenous} \\ \text{BOD} \\ \text{exerted} \end{bmatrix}
=
\left\{
\begin{bmatrix} \text{Nitrogenous} \\ \text{BOD from} \\ \text{upstream reach} \end{bmatrix}
+
\begin{bmatrix} \text{Nitrogenous} \\ \text{BOD in tributary} \\ \text{or wastewater} \end{bmatrix}
\right\}
\begin{bmatrix} 1-10^{-K_N t} \end{bmatrix}
\qquad (5)
$$

where
K_1 = First order carbonaceous deoxygenation rate constant

K_N = First order nitrogenous deoxygenation rate constant

t = Time of travel in reach

Volumes of water are visualized as moving downstream as distinct units (or "plugs"). Mixing, dilution, and biochemical reactions occur within the units as they move downriver, but because the system is assumed to be in steady state, the water quality of each unit passing by a given point is exactly like that which preceded it. For this reason, only one incremental volume of water needs to be modeled for the time of travel through the reaches of interest.

Assumptions and Limits

Any model is of value only within limited ranges based upon the restricting assumptions. Assumptions proposed by the US Geological Survey for such a model are considered reasonable for this study and are as follows.

1. Reaches of Rkm 139 to 8 are applicable.

2. Steady state conditions must prevail. The model is applicable to prediction of average daily DO concentration during low flow, high temperature conditions that have been preceded by at least 5, and preferably, 10 days of relatively stable streamflow and water temperature. This condition is approximated by mean August flows of typically dry summers.

3. The streamflow and water temperature must be for low flow between 85 and 255 m^3/s Salem gage and ±3°C of calibration conditions (20° C at Salem, 23°C at Portland), respectively.

4. Channel geometry must be similar to 1973-74 conditions. Isolated dredging or filling do not cause significant differences. In contrast, a 2-m deepening of the Portland Harbor would likely invalidate the present model and necessitate the collection of new channel geometry data.

5. The predominant wastewater loads must be from secondary biological treatment.

6. An approximate balance of DO production and DO consumption between photosynthesis and respiration by aquatic plants must be present (29).

DO problems have been historically most evident in the river's main stem between Rkm 8 and 139, below Salem. The problems occur in late summer when flow is low, temperature and metabolism rates high, and food processing wastes are discharged. Such knowledge allows more effective modeling effort and the use of the simplifying steady-state concept. Below Salem, reach partitioning has been carried out by the US Geological Survey (USGS) for this summer period (30). Above Salem and up tributaries there is less need to model DO. The main stem boundary conditions at Salem are established by routing down oxygen-demanding inputs. This is not done by the DO model, but by supporting models that employ first-order decay expressions for carbonaceous biochemical oxygen demand (CBOD) and nitrogenous biochemical oxygen demand (NBOD).

Hydraulic Data

Good USGS records exist for Willamette streamflow (61). Over 100 stream gaging stations have been established in the Basin. With main stem channel slope, USGS cross-sectional data, and appropriate discharge figures, an effective channel roughness (Manning's n) was determined by a search algorithm for the Willamette channel from Salem to the Newberg Pool.

This estimation of channel roughness allows changes in channel cross-section to be determined for low flow conditions other than those of 1973. In and below the Newberg Pool, channel geometry is fairly constant over the range of low flows. The depth of the Newberg Pool is maintained by Willamette Falls, a natural weir. Channel depths in the tidal portion of the river are controlled by the Columbia which in turn is maintained at fairly constant sum-

mer conditions by its own reservoir system.

Travel times from Salem to Rkm 8 obtained from Manning's Equation velocities decreased from approximately 24 to 9 days as Salem discharge varied from 88 to 255 m³/s, the range of low flow conditions explored in this study.

Willamette Falls

At Willamette Falls oxygen is entrained and dissolved. Multiple routes of overflow at the Falls make the estimation of reaeration difficult. At periods of low flow, the Falls may have very small discharges since water is routed through the fish ladder, hydroelectric turbines, and industrial facilities. For use in the model, a measurement of DO changes from above to below the Falls, August 1973, were employed (30). Reaeration was assumed to vary directly with discharge and DO deficit.

Inputs of Pollution

Point source wastewater discharge data are regularly collected by the DEQ. USGS work in 1973 and 1974 derived an independent point source data set suited explicitly to low flow DO modeling (29, 30). For this study, a data base of point source wastewater dischargers was compiled from DEQ data (9, 10). The DEQ data have historical continuity and would seem naturally to be preferred by State environmental planners. USGS data were used to supplement the point source data base. Where no appropriate data were discovered (typically the case for nitrogenous output from small municipal plants), an estimate was made.

To facilitate the comparison of pollution control strategies outlined in the study objectives, municipal wastewater treatment plant discharges were standardized by plant type. For each class of plants in the Valley, weighted mean CBOD and Kjeldahl N concentration was determined from summer 1973 records. The standardized concentration was then reapplied to each plant's output. Table 5 indicates the standardized effluent concentrations for eight methods of wastewater treatment. Model runs using actual August 1973 discharges and standardized discharges yielded the same main stem DO result.

Industrial wastewater discharges were not standardized as their natures vary widely. One nitrogenous input was given as an unknown industrial nitrogenous load near Albany. Presently its source is unidentified; it was discovered by a nitrogen mass balance of up-and-downstream river samples. Due to poor mixing of summer flow in this reach, however, fieldwork has not correlated this loading to any point source. The input may be due in part to subsurface flows from ponds in the Albany industrial park and/or ammonia traversing the Santiam from a paper mill (30).

Nonpoint pollution data are not easily compiled. For this study where a strategy of nonpoint pollution control was not evaluated, nonpoint inputs were taken to be equivalent point sources at main stem tributary mouths. Tributary municipal and industrial BOD's were routed to the Willamette. BOD's sampled at tributary mouths and not accounted for as decayed residuals from upstream wastewater discharges were treated as nonpoint inputs.

49

TABLE 5.   EFFLUENT CONCENTRATIONS OF BOD AND N
FROM MUNICIPAL TREATMENT PLANTS

Plant type*	BOD_5, mg/l	Kjeldahl N as N, mg/l
TFEF	19	10
ASEF	16	12
ASP	18	20
AS	20	20
TF	26	16
L	30	0
P	130	23
ASPL	17	0

*TFEF = Trickling Filter with Effluent Filtration;
ASEF = Activated Sludge with Effluent Filtration;
ASP = Activated Sludge Package Plant; AS = Activated
Sludge; TF = Trickling Filter; L = Lagoon; P = Primary;
ASPL = Activated Sludge Package Plant with Lagoon.

TABLE 6.   DEOXYGENATION RATE COEFFICIENTS

River reaches	Rate coefficients, base 10, per day	
	Carbonaceous	Nitrogenous
Willamette tributaries	0.06	0.1
Willamette above Salem	0.04	0.2
Salem - Newberg	0.05	0.4
Newberg - Willamette Falls	0.02	0.0
Below Willamette Falls	0.02	0.0

Benthic oxygen demand in the Portland Harbor was modeled as several immediate oxygen demands.

Rate Constants

First-order deoxygenation rate constants for both carbonaceous and nitrogenous biochemical oxygen demand have been determined by the USGS (29). Of particular interest are changes of carbonaceous deoxygenation rate constants from 0.10 - 0.14 (base 10) 20 years ago to 0.03 - 0.06 (base 10) presently. This is believed to result from the primary to secondary improvement of treated discharges.

Deoxygenation rates used in the model were determined by best fit and are given in Table 6. The rates closely agree with the values determined by the USGS independently of DO simulation.

Verification

Three sets of Willamette main stem DO field data exist for August 1973. All three data sets (Figure 16) illustrate the DO decrease, due in great part to nitrification, from Salem to the Newberg Pool (Rkm 140 to 84). The river roughly maintains its DO content in the pool (Rkm 84 to 43), reaerates as it passes Willamette Falls (Rkm 43), loses DO in the tidal pool, and recovers again when at last it is diluted with Columbia flow (not shown).

The ranges plotted in Figure 16 indicate diel oxygen fluctuation and/or sampling variation. It appears that this scatter is fairly regular and does not mask the overall DO profile. Plotted with the field data is the DO profile modeled for the same period. Subsequent model runs with varied discharge and loading provide DO profiles substantially in accord with reported values.

Sensitivity

The Willamette DO profile is generally insensitive to differences in USGS and DEQ point source data. Simulation trials indicated that the main stem DO profile is generally insensitive to altered BOD loadings when such changes are confined to a small number of discharges. Profile changes occur when large numbers of discharges are altered. This significantly affects the use to which the model may be put. Alternative environmental strategies must be modeled as significantly different net discharge loadings. There may indeed be some economic gain obtained by redistributing or reallocating fixed loads among several dischargers, but overall environmental impact is likely to be unaltered.

There exists one exception to the generality of DO's insensitivity to individual discharges. Large nitrogenous loadings in reaches of high nitrogenous deoxygenation rate constant can indeed influence the entire DO profile.

The DO profile is significantly influenced by river travel time. In initial simulation runs in which the lower reaches were not backwater, but rather assumed to flow at normal depth, travel time was unduly short at very low flows (100 m^3/s). As a result, the DO sag too small. The assumption of constant

51
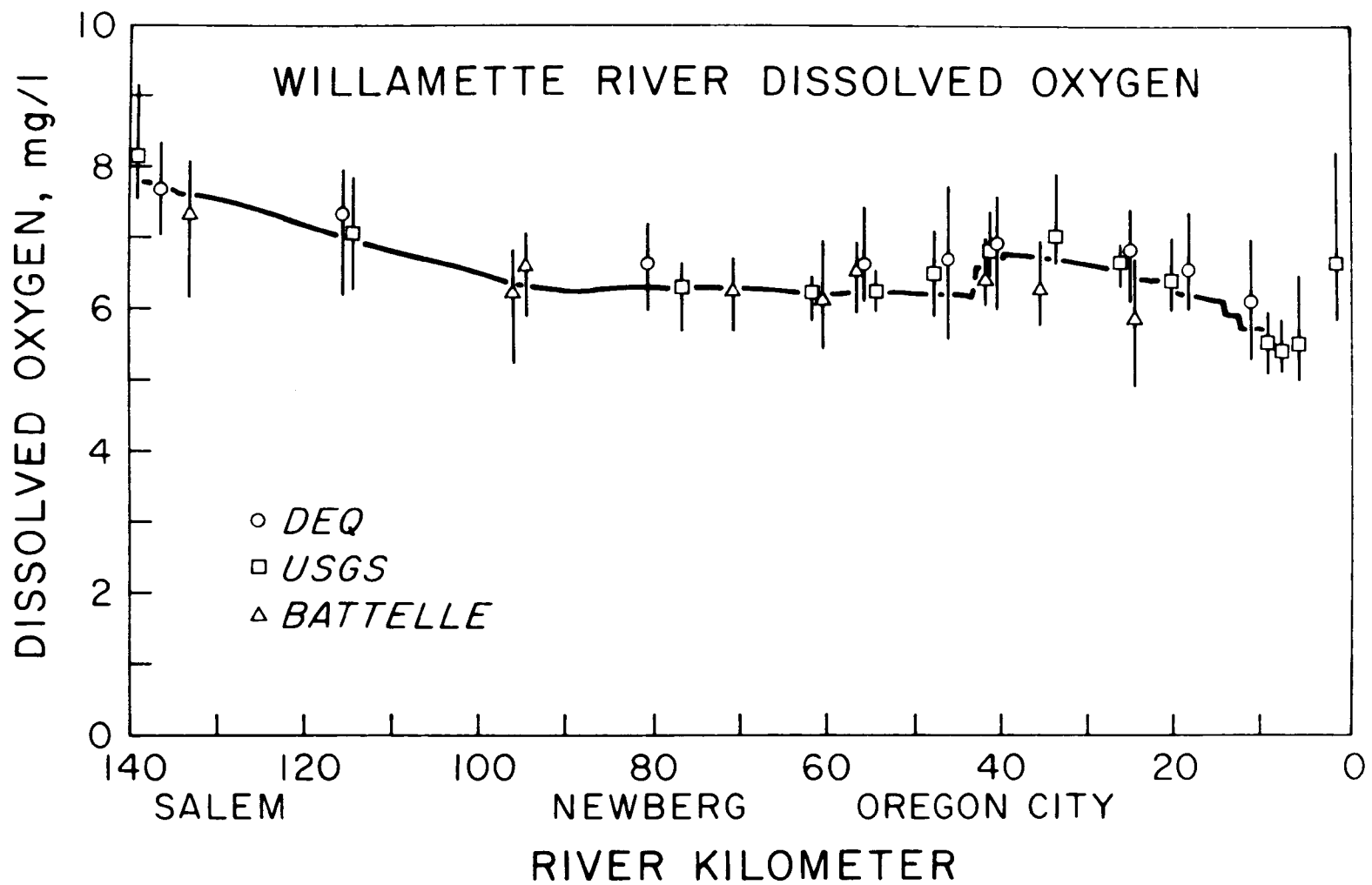
Figure 16. Dissolved oxygen simulation and verification, August 1973 (29, 57).

depth below Newberg corrected this anomaly.

Temperature variations of several degrees centigrade do not greatly alter the results. A 5 to 10°C increase, however, may depress the DO profile. Deoxygenation rate constants that were increased or decreased 10 percent did not greatly alter the DO profile under August 1973 conditions.

A DO Index

It was originally anticipated that three fixed levels of water quality would be considered: above, the same as, and below the DEQ Willamette standards (7 mg/l DO at Salem, 6 at Newberg, and 5 at Portland). In modeling it became evident that to match DO levels, an inordinate set of pollutant loadings would be needed for trial and error solution. Such an expansion of an already multidimensional study is of little general value. Rather, an alternative index of water quality was developed, comparing DO in reaches where sag would be most manifested to the actual DO of August 1973.

To generate a DO index the simulated DO levels are noted for 17 locations systematically spaced through the Newberg and tidal pools. The index is calculated as follows:

$$DO \text{ index} = \sum_i^n \Delta_i/n - zS + K \tag{6}$$

where Δ_i = DO simulated - DO standard at station i,

   S = standard deviation of Δ over sample size n,

   n = 17 stations spaced at 5 km from Newberg to Portland,

   z = normal statistic for a 90 percent one-sided confidence interval, 1.282 in this case, and

   K = correction constant.

The last term in Equation 6 is a constant shifting all values such that the index of actual 1973 conditions is 0 mg/l. To illustrate the meaning of this index, Willamette quality designated by an index of 0.3 mg/l indicates that from Portland to Newberg, 90 percent of the lower river is 0.3 mg/l or more above the DO levels of August 1973.

SUMMARY

A lower main stem Willamette DO model is selected as an environmental expression suitable for this study. The USGS field work and DEQ records provide necessary sources of model data. A model documented in Appendices B and C is developed to relate lower main stem DO detail to Basin-wide pollution control strategy. The model is designed for low-flow, steady-state conditions and summertime loadings of approximately secondary effluents. The Velz reaeration algorithm (Appendix C) satisfactorily accounts for the river's atmospheric oxygen inputs. A DO index is proposed allowing river DO profiles to be compared.

There appears to be significantly different reaction rates of low-flow NBOD exertion in Willamette reaches. CBOD rates are generally low. If travel times are not excessive, much BOD is discharged to the Columbia and not exerted in the Willamette main stem.

Inadequately documented nonpoint source loadings and benthic demands are roughly approximated in the model, but their true natures are largely unknown.

SECTION VII

ECONOMIC MODELING

MODEL SELECTION

Economic analysis provides a link between strategy for environmental quality and energy impact. The energy model expressed in this section translates direct dollar costs for pollution control ("direct" being contract price for treatment plant facilities, annual expenses for reservoir operation, etc.) to a direct energy cost (fuels consumed in construction and operation) and to a total energy cost (energy needed throughout the economy to create and supply the necessary materials for pollution control activity). Economic models for water pollution control strategy were used as estimators of direct dollar charges.

Criteria

Costs were charged to water pollution control if they represented expenses qualifying on tax or DEQ records as those of water pollution control and/or expenses reasonably expected to improve the summer dissolved oxygen quality of the main stem Willamette. Investment in Willamette wastewater treatment facilities and subsequent operation, maintenance, and replacement may or may not bring about an upgrading of the quality parameter of interest, dissolved oxygen. For DO to retain its role as overall water quality indicator, it is necessary to control other potential problems (e.g., suspended solids, metals, nutrients) concurrently. Though these pollution control expenses do not have returns seen in a DO model, they can be assumed to be advantageous to water quality.

Units and Partitioning of Cost

The units selected for economic modeling are constant 1973 dollars. Inflation is corrected for by the Construction Cost Index, as most direct expenses for pollution control are incurred in contract construction (62). This analysis does not address the issue of how inflation may be altered by pollution control expenditures.

Pollution abatement costs may be partitioned into two categories: variable costs and fixed or independent costs. The former class is made of those expenses that can reasonably be approximated as varying continuously and inversely with reduction in pollutant discharge. For variable cost a few more pollutants can be removed with the expenditure of a few more dollars. The second category is that of fixed or independent charges. These typically reflect costs associated with diversion of wastewaters from Willamette outfalls to the Columbia, summertime wastewater detention, land disposal, and prevention

55

of discharges. With such tactics, the characteristics of the waste are of no significance to the quality of the Willamette. The lack of that waste, though, is of potentially great consequence to the Willamette. Willamette quality behaves independently of fixed costs, once invested.

Costs associated with flow augmentation may be treated as variable or independent, depending upon how augmented flow is priced. If a fixed unit expense is attached to summer reservoir release (the common procedure in cost allocation), the charge is subsequently independent of the DO benefits afforded. On the other hand, if a price schedule is assigned to summer augmentation such that resultant water quality enhancement is priced, the charge is variable.

The partitioning of costs into variable and fixed categories helps identify qualitative differences in dollars invested for pollution control. The greater the ratio of variable to fixed dollars invested in a strategy of pollution control, the more flexible the strategy.

WASTEWATER TREATMENT COSTS

Costs for wastewater treatment activity include capital investment and operation, maintenance, and replacement (OMR) expense. Municipal treatment (including municipally treated industrial effluent); interceptor, outfall, and lift station provisions; industrial treatment having separate outfalls; and industrial pretreatments prior to discharge to municipal sewers were the tactics of wastewater treatment considered. Costs not considered included home plumbing, sewer laterals, and the stormwater portions of separated sewers.

Municipal Treatment

Cost functions for municipal waste treatment plants are typically of the form:

$$C = AQ^B \qquad (7)$$

where
C = capital or OMR cost,
Q = design plant discharge, and
A, B = constants.

Capital cost models selected from engineering literature indicate that the construction cost of August 1973 Willamette-discharging plants would be $54.1 million (63, 64, 65, 66, 67). This estimation does not include engineering expenses and abandoned portions of operating plants. A 1.24 correction factor was therefore applied to those A coefficients to fit them to the surveyed 1973 $67.2 million sum (3). The total OMR, labor cost, electricity cost, and chemical cost were likewise estimated by exponential functions. Table 7 lists A values corrected for the Basin and B values determined nationally for eight classes of wastewater treatment employed in the Willamette Basin. For these cost coefficients it is presumed that municipal plants are operated on a year-around basis. The DEQ pollution control policy would not allow certain plants to cease operation in the winter when river DO problems are absent.

TABLE 7. COEFFICIENTS A, B FOR COST MODEL (3, 63, 64, 65, 66, 67)

	$C = \$1000\ AQ^{B\dagger}$				
	Capital	Annual			
Plant*	construction	OMR Total	Labor	Electricity	Chemical
P	667.2,0.755	43.2,0.587	25.9,0.551	5.9,0.499	8.3,0.578
L	166.0,0.740	7.0,0.554	3.3,0.361	0.0,1.000	0.0,1.000
ASP	206.0,0.440	46.8,0.621	28.7,0.680	11.9,0.497	4.4,0.535
ASPL	226.8,0.469	51.5,0.599	31.5,0.680	11.9,0.497	4.4,0.535
AS	1264.4,0.771	64.4,0.730	38.0,0.767	15.0,0.558	5.6,0.674
TF	1114.2,0.592	42.3,0.621	25.6,0.662	6.5,0.553	6.2,0.510
ASEF	1536.6,0.771	89.8,0.730	42.5,0.767	16.9,0.558	5.6,0.674
TFEF	1386.3,0.592	67.6,0.621	32.0,0.667	8.1,0.553	6.2,0.510

*P = Primary; L = Lagoon; ASP = Activated Sludge Package Plant; ASPL = Activated Sludge Package Plant with Lagoon; AS = Activated Sludge; TF = Trickling Filter; ASEF = Activated Sludge with Effluent Filtration; TFEF = Trickling Filter with Effluent Filtration.

†C = 1973 dollars; Q = Plant design capacity in mgd (1 mgd = 0.0438 m^3/s).

Interceptors, Outfalls, Lift Stations

Wastewater interceptors, outfalls, and lift stations (IOFLS) and OMR cost for capital typically vary with capacity, discharge, length and slope of pipes, and degree of land development. Costs were determined from records.

It is assumed that 1973 Basin plants could be joined by trunk lines following connecting waterways. Flow would be with grade, minimizing lift requirements. To conform to the objective of evaluating treatment costs for 1973 strategies, trunk lines were sized for 1973 discharges, not estimated future flows. It was assumed that sewers proposed for regional alternatives would have the same proportional lift station cost as did the Valley's 1973 interceptor system. OMR costs for interceptors were estimated to be 0.4 percent of construction cost. Lift station OMR costs vary substantially with the unit. Survey results indicated that, outside of Portland, public works agencies spent 4.6 percent of their sewage treatment plant OMR on lift station OMR. This estimator was suitable for this study. To illustrate the relative natures of an IOFLS breakdown, Portland in 1974 spent $175,000 on interceptor and outfall OMR and $191,000 on lift stations. The rest of the Valley spent $175,000 on interceptors and outfalls and $146,000 on lift stations (3).

Industrial Treatment

Industrial pollution control costs can be itemized only on a plant-by-plant, process-by-process basis. Such a breakdown was not required for this study because the assumption was made that over the years the Willamette industrial complex has behaved like one large firm. A general pollution control cost function was then determined. Thirty years of records are available for industrial capital costs, BOD generation, and BOD discharge. Figure 17 shows that capital costs Basin-wide are exponentially related to the percentage reduction of industrial BOD discharge. Figure 17 exhibits a cost discontinuity at a BOD reduction of approximately 0.87. This degree of treatment corresponds to a switch from lagoons to activated sludge for the Basin's major industry, pulp and paper. At 90 percent BOD removal, activated sludge is more cost effective than an extrapolated lagoon system. If the relationship as shown on a linear scale rather than log-log, the curve would approximate the exponential form commonly used to illustrate pollution treatment expense. The discontinuity at the 0.87 level would not be apparent.

The use of such a model imposes limits on strategic pollution control planning. The data from which the model is constructed represent a reasonably consistent and monotonic industrial cleanup. An intraindustrial mechanism was assumed by which pollution cleanup was equitably shared by all the Basin's firms. For a particular environmental strategy with a net industrial discharge, the total cost can be estimated from the industrial cost model, and specific changes in wastewater discharge allocated in a manner proportional to current loadings. Costs for tactics of decreasing one plant's discharge and increasing to the same extent that of another could not be modeled by this approach. Such tactics are inconsistent with given goals of best practicable or available treatment for all dischargers. In cases where unique industrial changes are of interest, total industrial cost estimates would have to be modified.
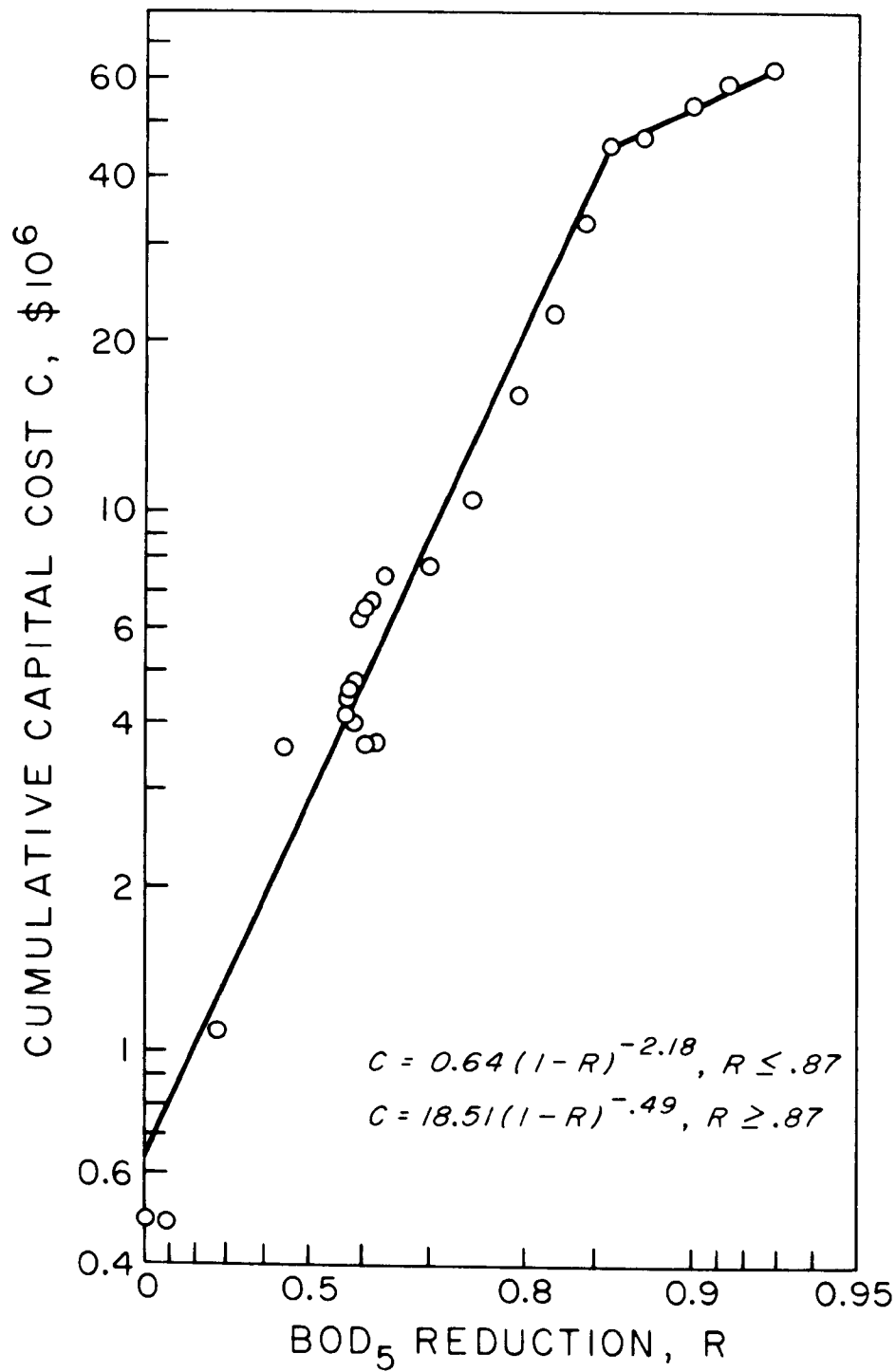
Figure 17. Industrial expenses for water pollution control, Willamette Basin (3, 25, 26, 27).

It was assumed that across the industry, reduction of CBOD is a reasonable estimator of reduction of other, less documented pollutants. A CBOD reduction is accompanied by a proportional change in NBOD. It was assumed that the unknown nitrogen input near Albany is a point source industrial discharge. If the cost of NBOD removing facilities were paid by the Basin-wide industry, this nitrogen source could probably be controlled.

Industrial OMR expenses are typically integrated with other production costs. The best overall estimate stems from industrial survey data that indicated that $3.3 million was spent by the firms as water pollution OMR expenses (3). OMR costs were assumed to directly vary with pollution control capital costs. Several Portland firms incorporated in Basin records discharge to the Columbia. These expenses were summed from DEQ records and recorded in the fixed or independent category. Records of Basin capital costs indicated approximately 3 percent of industrial capital costs fell into this category.

Industrial Pretreatment

Forty-five Basin industries in 1973 discharged to combined municipal systems. The end-of-line treatment expenses are incorporated in the municipal data and thus were not recounted. However, many of these industries practiced pretreatment before release to the sewers. Survey data on pretreatment revealed that capital expenses and OMR annual costs were of the same magnitude. Some firms may have no pollution control equipment, per se, but account some of their production OMR costs as pollution control. Total capital investment was estimated to be approximately $800 000; yearly OMR was $400 000. These costs were divided between Willamette and non-Willamette discharge in the proportions determined for municipal plants.

Abandoned Facilities

Costs of abandoned plants were taken from DEQ records. These facilities are typically package plants removed from service when sewers were extended from central facilities. In regionalization, some plants were removed from service and other plants expanded to serve the demand. In such a case, the value of the removed plant was recorded as a fixed, independent, abandoned facility. No salvage value was assumed. No OMR was associated with abandoned facilities.

LOW FLOW AUGMENTATION COSTS

A cost attributable to flow augmentation for water quality control may be derived in either of two ways. The first method estimates benefits foregone by other reservoir beneficiaries when flow is augmented for water quality control. A second method uses costs derived from expense data from the reservoirs. By allocation, a share of reservoir cost is assigned to the reservoir beneficiary, water quality.

Benefits Foregone to Other Water Uses

Willamette water uses have been identified in Section IV. Alterations in benefits due to changes in instream flow were investigated as part of an

evaluation of strategies. Table 8 indicates the probable effects on various water uses as a result of decreased and increased summer flow augmentation. Effects stem from both altered discharge and resultant water quality. A discussion of the construction of Table 8 is found in Appendix D. As indicated in Table 8, waste disposal and irrigation were the water uses most tangibly related to low flow augmentation. The competitive relation of the two uses, one instream, one consumptive, provided a benefits foregone estimation of augmentation's value for water quality. From Appendix D, $53 000 per m³/s represented a liberal extrapolation of what instream flow might be so worth.

Small or negligible complementary augmentation benefits are realized by several other water-related activities, but values are difficult to determine and are likely to be insignificant. In some cases, flow augmentation for DO control provides no real increase in benefits for other augmentation uses but does give a measure of added protection.

Charges to Reservoirs

Willamette low flow augmentation is recognized to be an effective strategy for water quality maintenance. Costs of such regulation are incurred in construction and operation of the Corps' multipurpose reservoir projects. A model of water pollution control's share of these expenses brings forth a problem different than the problems encountered in estimations of treatment costs or benefits foregone. In those models, data were often sparse, but the data dealt with unique objectives. A dollar spent for a treatment plant was a dollar spent for pollution control. For multipurpose reservoirs, a dollar spent may be an investment for recreation, hydroelectric power, and low flow maintenance. The charge for low flow control may yield improved navigation, irrigation, and pollution control. The problem is one of cost allocation to reservoir beneficiaries, only one of which is water quality. As discussed in Section IV, water quality is generally not an authorized reservoir purpose, and thus not assigned a cost in Corps' documents.

This investigation must depart from a viewpoint of no-cost flow augmentation for water quality control. If flow augmentation is allowed to compensate for some treatment, a strategy of explicit interest in this study, flow augmentation must be priced. Otherwise, as a seemingly free good, there is no reason economically to opt for anything less than the hydrologic upper limit of dilution flow. The problem of strategy would be moot.

The separable cost-remaining benefits method is used in the allocation of costs for Federal multipurpose water resource development, pursuant to a 1954 agreement among the Corps, Federal Power Commission, and the Department of the Interior. This method provides that each project be charged no less than the costs incurred only due to its inclusion in the project, no more than its benefits, and between these limits, a proportionate part of the savings stemming from the multiple-purpose project.

As developed in Appendix E, a reservoir charge to water quality control was allocated as:

TABLE 8. PROBABLE EFFECTS OF ALTERED LOW FLOW MAINTENANCE, WILLAMETTE RIVER*

Water use	Decreased low flow maintenance		Increased low flow maintenance	
	Lower discharge	Lower water quality	Higher discharge	Higher water quality
Municipal, Industrial	-	-	+	+
Irrigation	++	+	--	-
Navigation	-	0	+	0
Hydroelectric Power	-	0	+	0
Flood protection	-	0	+	0
Recreation	- River + Reservoir	- River	+ River - Reservoir	+ River
Waste disposal	--	--	++	++
Fish, wildlife	-	-	+	+

* Key: 0 Same benefits of river use.
    + Increased benefits of river use.
    - Decreased benefits of river use.
    Single sign indicates a general case, probably not significant on the Willamette.
    Double sign indicates a significant, tangible relationship on the Willamette, poten-
        tially suited to economic analysis.

$$C = 27\ A_{WQ}\ /\ (98 + A_{WQ}) \qquad\qquad (8)$$

where C = annual charge, millions of dollars, and

A_{WQ} = alternative annual cost of water quality control to yield a specified level of summertime DO in the lower Willamette, millions of dollars.

Because benefits of multipurpose reservoirs in effect subsidize one another, this cost model is sensitive to the value of hydroelectric power produced by the reservoirs. As shown in Appendix E, if power is valued at twice its 1973 price, the denominator in the equation would become $(109 + A_{WQ})$, decreasing the charge to water quality.

SUMMARY

A set of economic models were developed to provide costs in direct 1973 dollars for two approaches to water pollution control in the Willamette: treatment and low flow augmentation. Treatment costs included capital and operational expenses for municipal plants, interceptors, outfalls, lift stations, and industrial waste treatment and pretreatment. Treatment costs were categorized as variable, incrementally influencing Willamette water quality; or independent, having a fixed effect on the Willamette.

Low flow augmentation costs for water quality were expressed in two manners: the benefits potentially foregone to irrigation, or a portion of reservoir cost attributable to augmentation.

SECTION VIII

ENERGY MODELING

INTRODUCTION

In this section an Input/Output energy model is developed to express the energy requirements for Willamette pollution control strategies. There are several limits of the Input/Output approach and these limits, along with their implications for energy modeling, are discussed.

In most technical studies, a theoretical expression for modeling is rigorously developed in the body of the report and the details and procedures necessary to carry out the model are relegated to an appendix, or not published altogether. In this study, the emphasis is reversed. Input/Output analysis is currently a standard econometric method. An example of Input/Output development is included in Appendix F for illustrative reference. Expanding the ability to put to use the theory that already exists, rather than development of more complex models, is needed if energy modeling is to become a useful analytic perspective. Thus, this section focuses on a use of an existing Input/Output energy model.

DIRECT, INDIRECT, AND PRIMARY ENERGY

Strategies of environmental control require both direct and indirect energy. Direct energy is used as high grade fuel (coal, oil, gas) or power consumed in the final step of pollution control, e.g. electricity to build and run wastewater treatment plants. Indirect energy is required as high grade fuels consumed to mine the iron, to forge the steel, to fabricate the equipment, and to produce pipes or chemicals needed by the plant. If material flow can be traced from raw materials to final products, and if at each step of material transformation the consumption of high grade energy is known, indirect energy embodied in the final product can be estimated.

To assess the energy impact of pollution control alternatives, both direct and indirect energy requirements are of interest. Direct needs are of principal concern within a region where power is in short supply. An energy need for environmental control may compete with the need of some other energy-consuming activity, say industrial production. Indirect needs are of major concern to the economy as a whole, of which the region is but a part. Since it is probable that a trace of material flow will extend from region to the encompassing economy, much of the indirect energy requirements may be experienced outside of one region. If national energy stock is insufficient to meet all demands, the indirect energy requirement imposed by one region is energy consumption foregone by consumers in other regions. If the region im-

posing the indirect national demand also must compete nationally for its own direct energy supply, the indirect needs then compete against the direct needs of that very region.

To unify energy analysis of a large system, it is necessary to reduce energy costs to a common unit. The fossil fuel equivalent "primary" joule is selected as such a measure. This unit represents a joule of energy obtained from coal, oil, or natural gas. Where hydroelectricity or nuclear electricity is consumed, its fossil fuel equivalent is considered, i.e., the units of fossil fuels required to generate that quantity of electricity. Hydroelectricity taken for pollution control forces other power users to turn to fossil sources, thus all energy consumed is considered to be effectively a demand upon primary sources.

Primary energy cost for any activity is the equivalent final cost of that activity to the world's fossil energy stock. This cost is variously called the total cost or the direct plus indirect cost.

The term "total" energy cost has another popularized meaning that should be distinguished from the usage in this study. Total energy cost is at times considered to be the net flux of all types of energy quantified on a fossil fuel equivalent basis (51). Such accounting credits energy value to coal, gross plant production, sunlight, dollars, information, ocean currents, in short, the inputs to world systems. The "primary" unit employed in this investigation is less general. Primary energy is derived from fossil reserves or generated from hydroelectric or nuclear plants. Primary energy is transformed in the production sector of an economy and consumed as heat and light in households, mechanical friction in factories, fuel for autos, etc. Thus primary energy represents a subset of broadly-defined "total" energy.

INPUT/OUTPUT ANALYSIS

Input/Output analysis (I/O) is an application of general equilibrium theory to empirically interrelated activities. An open system is modeled as linearly interdependent sectors of production and consumption; coefficients relating each sector's output to inputs are assumed to be fixed. Perturbations of output from the total system yield shifts of production within the system. These internal shifts reflect the sector inflows and outflows necessary to satisfy new exogenous requirements, endogenous mass balance, and constant input-to-output factors. I/O analysis has been shown to be suitable for modeling flows of goods, money, pollutants, and energy (68, 69, 70, 71).

The basic I/O model for energy demand is illustrated in Appendix F. Included is a discussion of the double counting problem, a consequence of recounting transformed energy.

Model Expression

As developed in Appendix F, the solved I/O energy model is of the form:

$$\underline{E} = \underline{\varepsilon} \, \underline{Y} \tag{9}$$

where $\underline{E}$ = the primary energy consumed directly and indirectly,

$\underline{Y}$ = the final demand in dollars for goods, and

$\underline{\varepsilon}$ = a dollar-to-energy transformation, the "primary" energy coefficient.

In addition, direct energy demand can be expressed as:

$$\underline{E} = \underline{R}\ \underline{X}$$

where $\underline{E}$ = the energy directly consumed,

$\underline{X}$ = the total production in dollars of goods, and

$\underline{R}$ = a dollar-to-energy transformation, the "direct" energy coefficient.

I/O coefficients ε and R have been calculated by Herendeen and others for the U.S. economy in 1967 (72, 73). These values may be modified for a 1973 Willamette Valley study if conceptual limitations, time dependence and regional variance from the national I/O model are considered.

Conceptual Limitations

The energy I/O model is limited by assumptions and conventions. Technology and energy coefficients ε and R are not independent in any real economic system, although they are assumed so in the model. Fossil fuel equivalents of hydroelectric or nuclear power introduce a technological component into the primary energy unit. Dollar flow in times of unstable monetary systems, producers' prices rather than those of consumers, exclusion of capital formation from transaction data, technical coefficient variability, and no economies of scale all impose limits on I/O scope. Nonetheless, Input/Output analysis is econometrically useful for studies where projections do not extend far into the future and perturbations of demand are moderate.

Figure 14 in Section V traces a variety of energy flows in and through the Willamette Basin. Like much of the State energy policy discussed in that section, I/O deals with industrial production. An I/O model can only be used in a "total" energy analysis as partial specification of the industrial subsystem. I/O itself does not provide insight into the dynamic aspects of economic behavior.

Time Dependence

Energy I/O national models have been constructed semi-independently for the United States in 1963 and 1967 (75, 76). The latter analysis reflects improvement in technique and scope. Of 352 non-energy model sectors, 281 appear to have decreasing primary energy-per-dollar intensity. The mean energy-per-dollar change is negative, potentially resulting from dollar inflation and technical development. The mean change does reflect an economy of expanding dollar flow and limited energy, an overall trend that is anticipated to continue.

66

A similar test for trends can be made from lumped figures for national energy consumption and gross national product. Such a check weights industrial sectors by their production. Using current dollars, such a calculation yields an approximate 2 percent annual decrease in energy intensity from 1963 to 1967 and a near 3 percent downward rate from 1967 to 1973. This again agrees with expected development in an energy-depleting economy. The apparent net rate change with time (the rate change from minus 2 to minus 3 percent) may stem from a spiral of energy-based dollar inflation. As world fossil reserves are rapidly being depleted, it is probable that the minus 3 percent rate will continue in its downward trend. As this study deals with conditions of 1973 only, the approximately 3 percent deflation rate was judged as empirically proper to apply to 1967 total energy (per dollar) coefficients.

If energy coefficients were projected to future years, an improved theory of energy deflation would be required. A 1967-to-1973 correction for I/O coefficients ϵ and R is a 6-year compounded 3 percent deflation applied to 1967 energy/dollar ratios. The issue of energy inflation is illustrated in the following example. Note that although the energy cost rises, the dollar cost rises more rapidly.

Cost of hypothetical project in 1967 ....$1 000
1967 I/O primary energy coefficient .... 100 MJ/$
Energy cost from 1967 I/O .... 100 000 MJ
Cost of same project in 1973 .... $1 771
1973 I/O coefficient $(100 \times (1-0.03)^6)$.. 83 MJ/$
Energy cost in 1973 .... 147 519 MJ

Regional Variation

I/O is best applied to a well disaggregated economy in which each sector receives a large portion of inputs from industries also within the economy. Subnational I/O models often have aggregated sectors with industries lumped enough together such that intersectional material flow, the crux of I/O analysis, is not trivial.

Two economic I/O regional models applicable to the Willamette region have been developed. An I/O economic model exists for the Willamette Valley, containing only four sectors. It affords little chance for analysis of specific sectors. It is of value in identifying the Basin's general import-export structure and for limited general economic projections (77).

A State of Oregon model exists for 1963 (78). In this model Oregon's industries are grouped into 29 sectors. The study is primarly an illustration of method rather than a definitive planning effort. A general check for regional disconformity can be abstracted from this model. State intraindustrial direct and indirect dollar requirements (diagonal $(I-A)^{-1}$ in Appendix F) can be compared to those of the nation. If they appear to be somewhat alike, the overall impact of a dollar spent in Oregon is similar to the overall impact of a dollar spent in the national economy.

Two sectors in the Oregon model are of particular interest to pollution control strategy: maintenance and repair construction (MRC); and electricity,

water, gas, and sanitary services (EWG). Thre is no sector in the Oregon model corresponding to construction. The State-modeled MRC sector produces $1.00746 of output per $1 sold to final demand. Corresponding national coefficients for two sectors combined to form the State classification are 1.00186 and 1.00737. For state EWG, the requirement is $1.00225. The agreement between the two I/O tables is reasonable. In these two pollution control activities, the regional and national economies behave somewhat alike.

Because pollution control in Oregon appears to be economically similar to that of the nation, it is hypothesized that the Basin's environmental regulation is in energy terms like that of the nation, especially when extra-Basin indirect impact is considered. A national energy I/O model is thus useful for regional study. Additional confirmation of the suitability of national energy I/O models was obtained from Willamette pollution control survey data. Direct energy requirements for construction and OMR were derived from detailed material-use records and fell typically within ±50 percent of the I/O direct prediction, the scatter anticipated nationally (70).

SECTOR ASSIGNMENT

In Section VII direct economic costs for water pollution control were modeled. The estimated costs correspond to the productions X and Y used in I/O energy analysis. The problem now remains of assigning to the pollution control costs the appropriate ε or R transformation coefficients.

Table 9 lists activities of Willamette River pollution control, the national I/O sectors to which they were assigned for energy modeling, and the resultant transformation coefficients, corrected to 1973. A discussion of how specific sector assignments were made, and how coefficients were determined to encompass the Basin's industrial production follows.

Pollution Control Activity

No economic sectors of the national I/O energy model are uniquely suited to activities of treatment plant construction, reservoir operation, and the like. The national breakdown of 368 sectors tends to disperse parts of such activities into various classifications. OMR costs for wastewater treatment might fall into: maintenance and repair construction other than for non-farm residential buildings (national I/O sector 1202); water and sanitary services (6803); or local government enterprises other than passenger transit or electrical utilities (7903). Each of these sectors reflects partly the pollution control activity of interest and much activity not of concern.

From intermediate energy I/O tables, discriminatory information may be abstracted about the 368 categories (73). The direct energy coefficients, R, are of particular interest. Survey data indicates that Willamette sewage treatment plants are almost exclusively powered by electricity (3). Coal is of zero direct use. Of the three likely I/O sectors, 1202 is primarily directly fueled by petroleum, 6803 consumes coal directly, and 7903 is mainly electrically powered. The latter sector, therefore, was judged as best incorporating OMR for Willamette sewage treatment plants.

TABLE 9. INPUT/OUTPUT DIRECT AND PRIMARY ENERGY COEFFICIENTS

| Activity | Construction | | | OMR | | |
| | Sector | MJ/1973 dollar | | Sector | MJ/1973 dollar | |
		Direct	Primary		Direct	Primary
Municipal treatment	1103	9.81	58.49	7903	52.11	89.91
Interceptors, outfalls, lift stations	1104	14.39	39.22	7903	52.11	89.91
Industrial pretreatment	1103	9.81	58.49	*	35.34	81.22
Industrial treatment	1103	9.81	58.49	*	35.34	81.22
Reservoirs	1105	12.48	40.76	7804	16.29	31.10

* National sectors combined to approximate Willamette industrial production.

Reservoir OMR, a Federal activity not exclusively assigned an I/O sector, is energetically approximated by the miscellaneous Federal activity sector 7804, a sector unintensive in operational energy needs.

The construction energy requirements for industrial pre-treatment tactics were assumed to be approximately equal to those of municipal treatment. The energy requirements for OMR pre-treatment tactics including process modification should be approximately those incurred in regular industrial production. Weighting 32 Basin industries by value of output and identifying from I/O sectors the appropriate industrial energy requirements, a Basin-industry OMR energy requirement was calculated.

Interceptors, outfalls and lift stations OMR was assumed to be similar in energy intensity to municipal plants. Per OMR dollar, more energy is directly purchased in these activities than in any other general pollution control measure.

Energy requirements for capital construction are easier to estimate than those for generalized OMR. Independent of I/O analysis, direct energy requirements for various construction activities have been estimated (80). Information specific to the pollution control tactics can then be used in place of the nationally based I/O direct coefficients for regional construction energy intensity.

Construction energy direct requirements were estimated from both literature and Willamette Valley construction records (3, 80). Treatment tactics were best identified in the I/O sector 1103, construction of public utilities. Again, industrial treatment works were assumed to require the same input mix

in construction as did municipal works. Interceptors, outfalls, and lift sta-
tion construction were similar in energy inputs to the highway construction
sector 1104. Reservoir construction was placed in the category of new con-
struction, other, 1105.

Irrigation Foregone

The option of valuing flow augmentation as irrigation foregone lends it-
self to an I/O conversion, but the result is different than those of dollar
expense. Increased irrigation may yield an increase in the Basin's economic
activity. In Appendix D, a \$53 319 per m^3/s direct value is assigned to Willa-
mette abstraction over the irrigation season. This figure, treated as benefit
foregone if flow is withheld from the fields, may be I/O translated to pri-
mary energy not spent for increased agricultural production. Thus, water not
diverted for irrigation represents both income not realized for Valley farmers
and demand not exerted on primary energy resources.

Whereas the dollars foregone might legitimately be seen as a cost, the
energy not mined cannot be truly interpreted to be a benefit. No energy im-
pact was credited to non-irrigation.

Comparisons

The magnitudes of I/O coefficients in Table 9 reveal relative energy
costs of various pollution control activities. These values can be compared
intuitively. In direct construction, energy intensity is lowest for treatment
facilities; gasoline and electricity to build a treatment facility represent
only a small part of a contractor's expense. Interceptors and reservoirs,
earthmoving endeavors, are higher in fuel per dollar intensity. Based on the
ratio of direct to primary energy for construction, treatment has greater
spinoff energy impact; the longer economic chain associated with the mechani-
cal and high-grade material inputs requires a greater overall energy input.
For interceptor and reservoir construction, roughly 30 percent of the primary
energy impact is realized directly. For treatment facilities, the ratio is
approximately 17 percent.

In the OMR columns, the greatest direct energy requirements are exerted
by municipal facilities. Industrial treatment requires less direct power, as-
suming production can be modified for wastewater control. Reservoir operation
requires a relatively small amount of power. Though municipal and industrial
tactics have different direct OMR coefficients, the total coefficients are
more nearly the same. This suggests that once a dollar is spent, it is likely
to eventually trace similar paths. Much of the OMR municipal and industrial
dollars are spent for energy-intensive chemicals. The reservoir primary co-
efficient is low. A dollar here is less likely to be spent for a series of
energy-expensive materials; it is more likely to be payment for labor and
quickly dissipated to the household sector.

SUMMARY

An energy Input/Output model is selected to express the energy impact of
the Willamette water quality control strategy. The model transforms dollar

expenses for various pollution control activities to both direct ("on the job") and primary ("from the earth") energy costs.

I/O models can be used to describe the economy best if supplies and demands are steady. I/O is not suited for projections of energy impact when technology is rapidly changing. This was not judged to be a difficulty for this study since most treatment and construction technology of 1967, the base year for the I/O model, was similar to the treatment and construction technology of 1973, the year under study. With correction for overall dollar-to-energy inflation, the I/O national energy model yielded dollar-to-energy coefficients suitable for the Willamette case in 1973.

Appropriate sectors for Willamette pollution control activities are identified. The resultant I/O coefficients revealed that per dollar of environmental control expense, the energy impact varies with activity. This provides an energy criteria for evaluation of pollution control strategies. The determination of which strategy can purchase a given level of water quality with the least amount of energy is explored in the subsequent section.

SECTION IX

ANALYSIS

INTRODUCTION

In previous sections, the Willamette Basin and its interrelated environmental, economic, and energy resources have been discussed (Sections III to V). Models have been developed expressing environmental, economic, and energy consequences of water pollution control (Sections VI to VIII). This section defines the range of pollution abatement strategies over which the consequences of such strategies are modeled, summarizes the modeling procedure, and then summarizes the results of analysis.

TREATMENT-AUGMENTATION MATRIX

Wastewater Treatment Levels

Eight alternatives for wastewater treatment are specified. Tables 10 and 11 list by treatment alternative municipal, industrial, nonpoint and benthic Willamette oxygen demands. Designated A through H in order of pollutant removal degree, the treatment alternatives do not represent every step of the regulation, but rather an increasing series of pollution abatement tactics. Level A represents a heavily polluted river, not improved since the 1950's. Level H indicates a complete abatement of oxygen-demanding point discharges. Level D represents the actual base period of August 1973.

Levels A and H are not reasonable alternatives for water pollution control in the 1970's. Neither extreme is modeled well, as assumptions of environmental condition (e.g. secondary-type wastes in river) or technological consistency (e.g. energy coefficients suited to 1973) are likely violated. Nonetheless, these two treatment extremes give perspective to consequences of middle degree treatment alternatives deemed to be more reasonable.

Levels C, D, E, and F represent secondary treatment tactics consistent with recent and near future probable Oregon regulation. Level G represents a major effort at industrial nitrogen control, an area of regulation only presently being effectively incorporated into DEQ planning (81). In Appendix G a description of each treatment level is given.

Flow Augmentation Levels

Four levels of low flow augmentation are used in the water quality modeling. A Salem discharge of 88 m^3/s represents a typical unregulated Willamette dry year low flow, as shown in Figure 7. A flow balance for August 1973 in-

72

TABLE 10. SUMMARY OF TREATMENT LEVELS

Strategy	Treatment level	Municipal plant types*	Industrial BOD$_5$, KjdN removal		NPS	Benthic
Less Treatment 1973	A	P, L	52%	0%	August 1973 loading	August 1973 loading
	B	P, L	81%	23%		
	C	AS, TF, L	90%	30%		
	D	L, ASPL, ASP, AS, TF, ASEF, TFEF	94%	33%		
More Treatment	E	L, ASPL, ASP, AS, TF, ASEF, TFEF	95%	46%	83% loading	83% August 1973 loading
	F	ASEF, TFEF, ASPL, ASP	95%	46%		
	G	ASEF, TFEF, ASPL, ASP	95%	90%		
	H	Unspecified	100%	100%		

* TFEF = Trickling Filter with Effluent Filtration; ASEF = Activated Sludge with Effluent Filtration; ASP = Activated Sludge Package Plant; AS = Activated Sludge; TF = Trickling Filter; L = Lagoon; P = Primary; ASPL = Activated Sludge Package Plant with Lagoon.

TABLE 11. SUMMARY OF RIVER LOADINGS

Treatment level	Municipal		Industrial		NPS		Benthic	Total	
	BOD$_5$	KjdN	BOD$_5$	KjdN	BOD$_5$	KjdN	IOD	BOD$_5$	KjdN
A	42998	7540	149039	24120	16860	943	1361	208897	32603
B	42998	7540	59616	18629	16860	943	1361	119474	27112
C	12457	5742	29808	16799	16860	943	1361	59125	23484
D	12252	5737	19872	16189	16860	943	1361	48984	22869
E	6613	5080	15897	12951	16860	943	1134	39370	18974
F	5764	3780	15897	12951	16860	943	1134	38521	17674
G	5764	3780	15897	2473	16860	943	1134	38521	7196
H	0	0	0	0	16860	943	1134	16860	943

dicates that without augmentation, this discharge would have taken place. Statistical analysis gives the same result (61). Discharge above 88 m^3/s may therefore be designated as augmentation derived from reservoirs.

The August 1973 mean discharge of 186 m^3/s represents augmentation under the present water quality control strategy. This discharge is that called for by the Corps to facilitate navigation and the State Water Resources Board to protect fish life (35). A 126 m^3/s discharge represents a level of decreased augmentation. Boating or fisheries would not significantly suffer at this flow if water quality were maintained. An upper limit to augmentation from existing reservoirs is estimated to be 255 m^3/s. This discharge would call for reservoir rule curves to be modified for rapid, late-summer drawdown.

With 8 levels of treatment and 4 levels of flow, 32 alternatives for pollution control can be investigated. This 4 x 8 matrix provides the basis for environmental, economic and energy comparison of water quality control strategies.

Response Surfaces

The response surface is a graphical alternative to data representation in matrix form. A response surface can be envisioned as a 3-D surface suspended above a 2-D base. The base here is a Cartesian plane defined by coordinates of wastewater treatment and river discharge. The height of the response surface above any point on this base represents the environmental, economic or energy consequence corresponding to the treatment-augmentation pair. The surface may be displayed in the same manner as contour lines on a topographic map.

Advantages of the response surface representation over a matrix display are several:

1. More data may be represented than only those pertaining to certain matrix columns and rows,

2. Data may be visually interpolated,

3. Trends may become apparent, and

4. The response surfaces may be directly employed in subsequent decision making analysis.

ENVIRONMENTAL ANALYSIS

Table 12 lists by discharge and treatment the simulated mean DO deviations, the standard deviation of those differences, and the 90 percent index defined in Section VI. In cases where the standard deviation is small, the simulated DO profile is roughly parallel to the 1973 standard. Where the deviation is large, the index is substantially lower than the mean difference; this results from the sensitivity of the index to the worst 10 percent case. The H option with a flow of 255 m^3/s is eliminated as offering nothing in incremental DO benefit above that achieved with 186 m^3/s. Three options of low

74

TABLE 12. DO MEAN DIFFERENCE, STANDARD DEVIATION, AND INDEX (mg/l)

Mean August discharge m^3/s	Treatment level							
	A	B	C	D	E	F	G	H
255	-1.03 0.69 -1.91	-0.16 0.30 -0.54	0.41 0.05 0.35	0.50 0.06 0.42	0.74 0.10 0.61	0.81 0.11 0.67	1.37 0.08 1.27	
186	-2.46 1.29 -4.11	-1.01 0.53 -1.69	-0.13 0.08 -0.23	0.00 0.00 0.00	0.36 0.05 0.30	0.43 0.06 0.35	1.15 0.14 0.97	1.62 0.20 1.36
127		-2.43 0.83 -3.49	-1.02 0.19 -1.26	-0.77 0.11 -0.91	-0.25 0.05 -0.31	-0.16 0.05 -0.22	0.80 0.29 0.43	1.60 0.19 1.36
88			-2.17 0.34 -2.61	-1.75 0.29 -2.12	-0.98 0.20 -1.24	-0.91 0.17 -1.13	0.38 0.41 -0.15	1.46 0.27 1.11

TABLE 13. TREATMENT, AUGMENTATION AND TOTAL ANNUAL COSTS
($ x 10^6 , 1973)
Flow Augmentation Cost Allocated

Mean August discharge m^3/s	Treatment level							
	A	B	C	D	E	F	G	H
255	16.14 3.66 19.80	19.41 2.14 23.68	27.57 5.93 33.50	30.11 6.00 36.11	35.64 6.41 42.05	37.45 6.55 44.00	38.33 8.87 47.20	100.00
186	16.14 1.76 17.90	19.41 2.14 21.55	27.57 2.73 30.30	30.11 3.04 33.15	35.64 4.31 39.95	37.45 4.28 41.73	38.33 7.87 46.20	100.00
127	16.14 0.56 16.70	19.41 1.28 20.69	27.57 2.03 29.60	30.11 1.89 32.00	35.64 0.74 36.38	37.45 0.34 37.79	38.33 4.51 42.84	100.00
88	16.14 0 16.14	19.41 0 19.41	27.57 0 27.57	30.11 0 30.11	35.64 0 35.64	37.45 0 37.45	38.33 0 38.33	100.00

treatment and low flow are eliminated because river quality would go anaerobic.

Figure 18 transforms the index variable of Table 12 into a response surface. The gradient of DO is positive, but decreases from left to right and bottom to top. With increase of treatment and/or augmentation, there appears to be decreasing returns of environmental improvement. Since the 1973 DO was typically 6 mg/l (Figure 16), the flattening of the surface at higher elevations is explained in part by an asymptotic approach to the DO saturation limit.

ECONOMIC ANALYSIS

Modeled treatment costs for treatment levels A to G are tabulated in Appendix H. Treatment cost for level H, "complete" treatment, is projected from general, national figures discussed in Appendix G. Treatment total costs, A to H, may be read from the bottom line of Table 13.

As noted in Section VII, flow augmentation costs might be determined by two methods: a charge for water diverted from irrigation, or a charge allocated to reservoir expenses. Flow is valued in both manners.

Augmentation Cost Allocated

Table 13 includes within each treatment-augmentation pair an allocated charge for water quality flow maintenance. This charge is determined by using Figure 18, the DO index response surface, to find the treatment level that would provide the same index quality at no augmentation. The cost of this treatment less the cost of treatment with augmentation is the alternative cost to augmentation. Allocated according to the separable cost, remaining benefit method proposed in Appendix E, Table 13 results. The allocated cost of augmentation generally increases from left to right. Exceptions to this trend occur where alternative costs are small.

The sum of treatment and allocated augmentation charges is the dollar response surface, Figure 19. The move from level G to H is the most costly of the given steps in pollution control.

A general assumption of pollution control strategy is here reiterated. In lieu of flow augmentation, point source wastewater treatment facilities would be constructed to mitigate dry year summertime DO depletion. In compliance with law, these facilities would be operated throughout the year, not solely during low flow periods.

Augmentation Unit Priced

If augmentation is valued at a fixed unit price, say \$5/af (af = 1233 m^3) as suggested in Appendix D and Section VII, Table 14 is obtained. Although treatment costs are as before, augmentation costs are not related to treatment savings, but rather to discharge level alone.
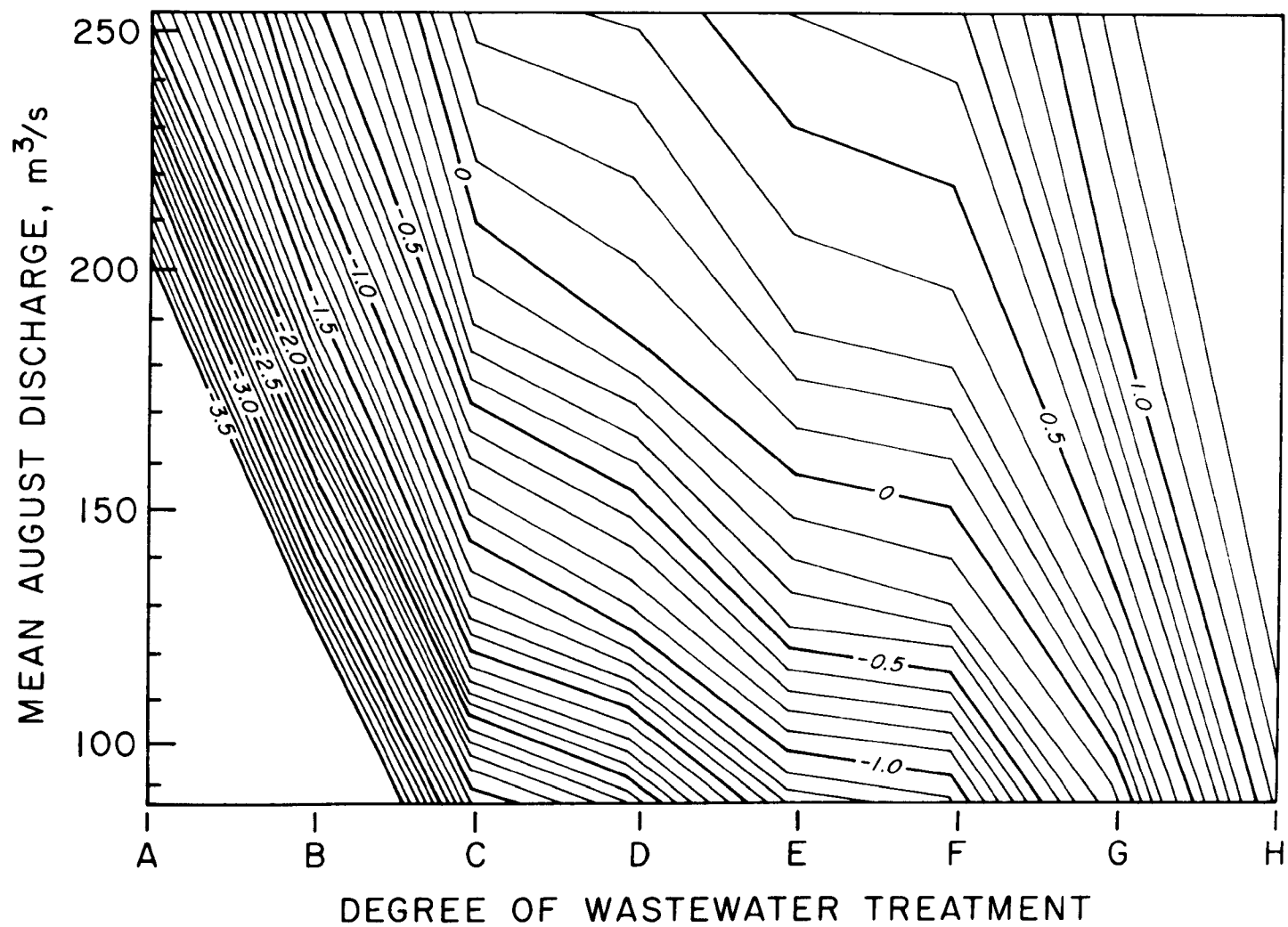
Figure 18. DO index response surface, August 1973, mg/l.
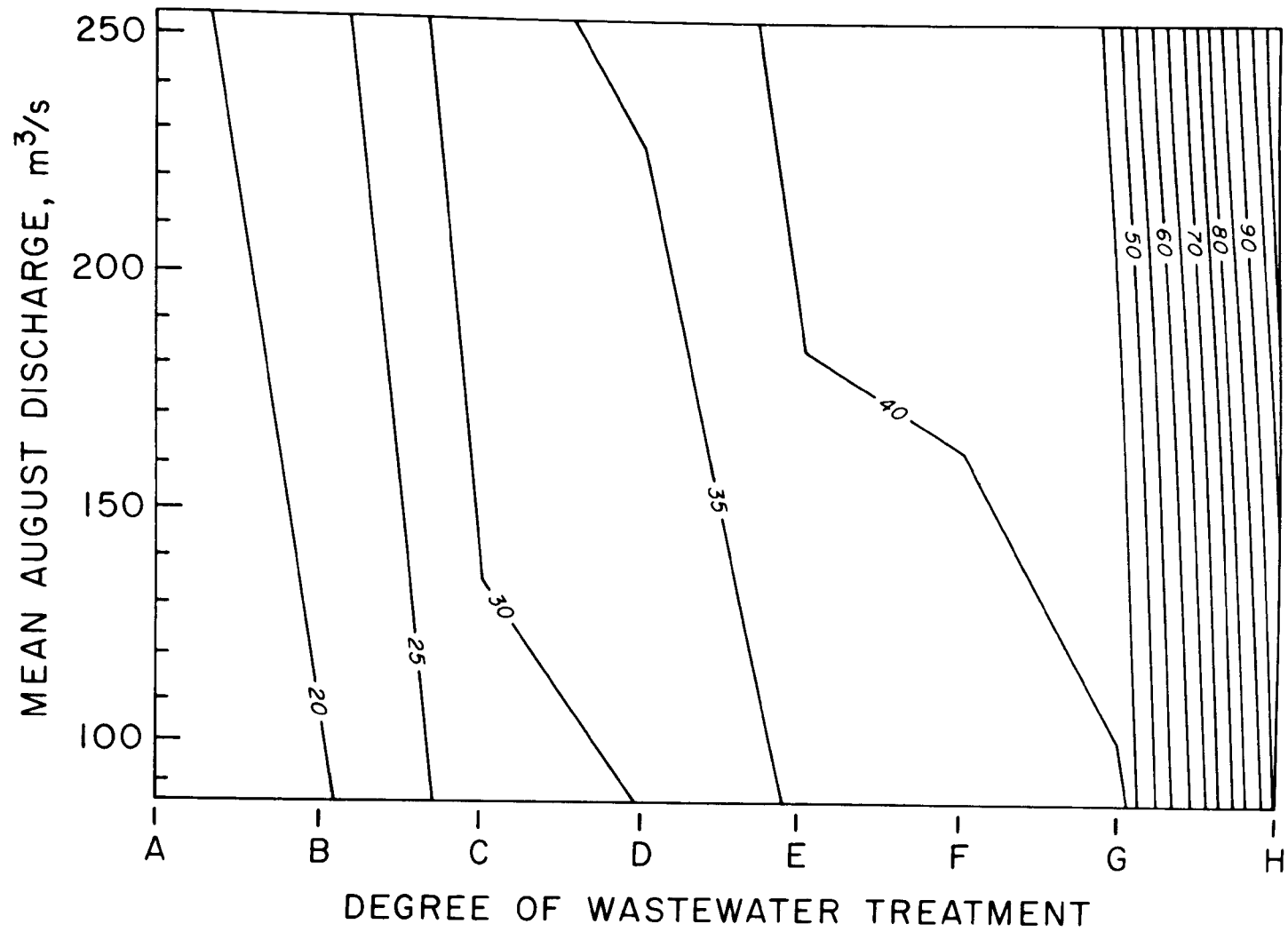
Figure 19. Annual cost of water quality control response surface, flow augmentation cost allocated, $ x 10^6.

TABLE 14.   TREATMENT, AUGMENTATION, AND TOTAL ANNUAL COSTS
($ x10^6, 1973)
Flow Augmentation $5/af

Mean August discharge m^3/s	Treatment level							
	A	B	C	D	E	F	G	H
255	16.14	19.41	27.57	30.11	35.64	35.45	38.33	
	8.86	8.86	8.86	8.86	8.86	8.86	8.86	
	25.00	28.27	36.43	38.97	44.50	46.31	47.19	100.00
186	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	5.19	5.19	5.19	5.19	5.19	5.19	5.19	
	21.33	24.60	32.76	35.30	40.83	42.64	43.52	100.00
127	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	2.10	2.10	2.10	2.10	2.10	2.10	2.10	
	18.24	21.51	29.67	32.21	37.74	39.55	40.43	100.00
88	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	0	0	0	0	0	0	0	
	16.14	19.41	27.57	30.11	35.64	37.45	38.33	100.00

Figures 20(a) and (b) and 21(a) and (b) illustrate cost response surfaces for water quality control at four prices of augmentation. In Figure 20(a), flow is free, thus imposes no cost on environmental strategy. Figure 20(b) plots the data of Table 14, the $5/af condition. In Figure 21(a) and (b), flow is valued at $10 and $20/af, respectively. As price rises, the response surface becomes more controlled by degree of augmentation.

Decision Making and Expansion Paths

The DO and economic response surfaces provide a basis for cost-effective environmental regulation. If the DO surface and a cost surface are superimposed, a path from left to right can be identified wherein for any given total annual charge, the maximum attainable DO index is achieved. Likewise, for any given DO, the corresponding cost is minimized. The procedure is standard in microeconomic analysis: treatment and augmentation are factors of production; the DO index and cost response surface contours are output and input isoquants, respectively; and the cost effective route of DO improvement is the expansion path (82).

Expansion paths, therefore, represent the efficient allocation of resources yielding incremental improvement toward an objective. If pollutant production were to always remain at 1973 levels and regulation were solely directed toward maximization of instream DO index, an expansion path on a treatment-augmentation plane would indicate how treatment and augmentation should be simultaneously employed. In this study, no assumption is made that 1973 waste production is fixed over time. Therefore, a treatment-augmentation expansion path here represents not a continuous-in-time best route for DO maximization, but rather a focus of points useful for evaluating the tactics of 1973. The closer the actual 1973 strategy is to the expansion path, the more cost efficient is that strategy.

Expansion paths are identified for DO control at $0, $5, $10, and $20/af charges for augmentation. The results are shown in Figure 22. Several generalizations may be drawn from that figure. If water were free, logical DO control would call for immediate maximization of augmentation and then step by step construction of treatment facilities. If water not used for augmentation were valued at $20/af, the cheapest DO improvement comes from treatment through level G before augmentation is initiated. These two extremes are respectively expressed by the expansion paths following the upper and lower boundaries of Figure 22.

With water priced at $5/af, augmentation should be maximized before treatments B, C, and D are purchased, but as steps E, F, and G are added, some augmentation can be cut back, saving its charge. At $10/af the expansion path is similar, but augmentation should be held at an intermediate value and then reduced.

All paths indicate that if the Basin were regulated near treatment level H, augmentation should be maximized, since the DO returns from augmentation would be much greater than the incremental DO returns from such high and costly marginal wastewater treatment.
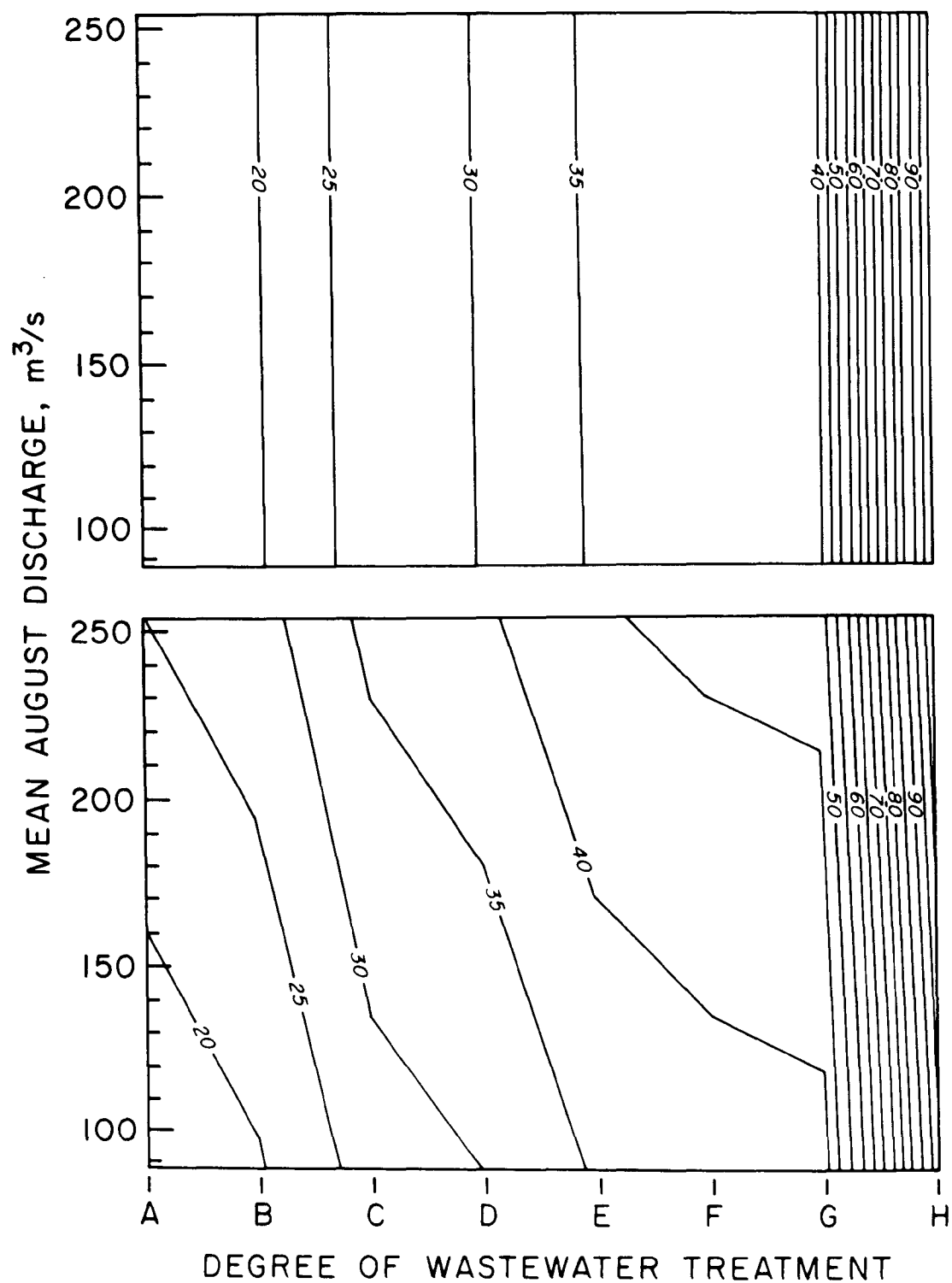
Figure 20. Annual cost of water quality control response surfaces, flow augmentation (a) $0/af and (b) $4/af, $ x 10^6.
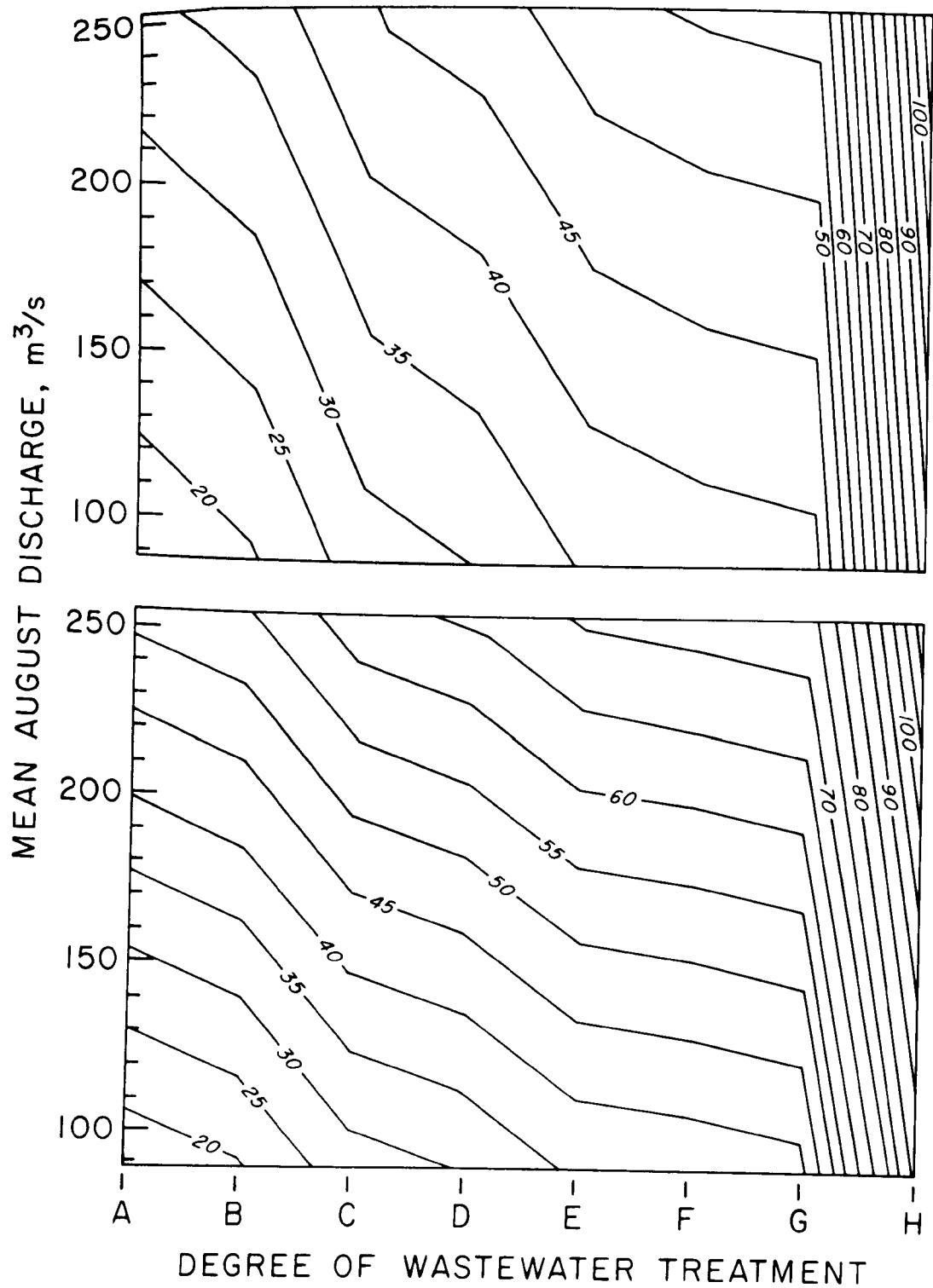
Figure 21. Annual cost of water quality control response surfaces, flow augmentation (a) $10/af and (b) $20/af, $ x 10^6.
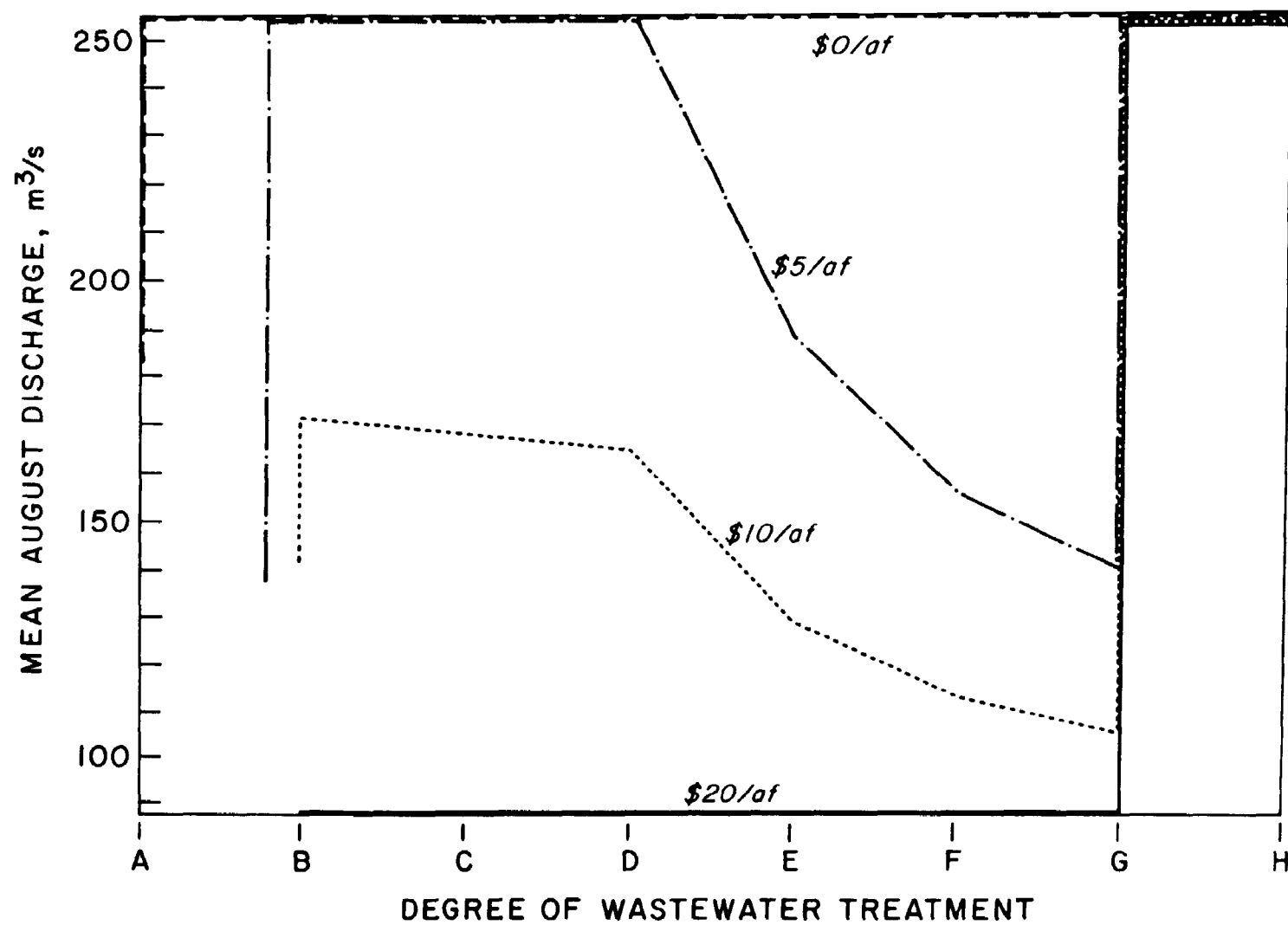
Figure 22. Expansion paths for water quality control, flow augmentation at four prices.

What is shown by an expansion path is the most efficient ascent up the cost and environmental quality response surfaces. What is not shown is how steep that route might be. Somewhere, gains (or losses) in environmental quality will be halted when society deems marginal costs and returns are balanced.

Figure 23 plots the total annual costs of water quality control against the DO index (a) for the case of fixed pricing and (b) for the case of allocated charges. In both figures, augmentation is fixed at four levels and varies determined by the cost efficient expansion path.

In Figure 23 (a), flow levels alternate in order of total cost as DO is improved. The bottom line always plots the expansion path gradient, defining the minimum boundary for the family of cost-DO curves. The changing order of the fixed augmentation curves illustrates the same results as did Figure 22. Levels of augmentation should vary in efficient upgrading of river quality.

From Figure 23(b), augmentation cost allocated is cost-efficient at the maximum level of flow. From Figure 23 a rather broad observation may be drawn: the total cost per DO return is basically of the same shape whether augmentation cost is cost allocated or unit priced, or whether pollution control is cost efficient or is accomplished with a fixed level of augmentation. As the DO index is brought up to -1, costs do not rise sharply. As the DO index is raised to 0 or +1, costs tend to soar. Willamette DO control strongly exhibits decreasing returns to scale.

ENERGY ANALYSIS

The Input/Output energy model applied to the costs of pollution control yields the primary energy costs of that control. As indicated in Section VIII, the allocation method for augmentation charge is preferred over an irrigation benefits foregone approach for primary energy study.

Table 15 lists total dollar, direct costs, and primary energy costs for the 8 treatment levels. Capital and OMR expenses are included for comparison. The data from which this table is constructed are listed in Appendix H. Tables 16 and 17 indicate the energy effects of flow augmentation, cost allocated. Figure 24 plots these tabulated data as (a) direct and (b) primary energy response surfaces.

A brief comparison of the dollar costs (Figure 19) to the energy costs (Figure 24) revealed much the same pattern of contour. The energy isoquants of Figure 24 were somewhat more vertical than the dollar isoquants of Figure 19, because augmentation is generally less energy intensive than treatment. The overall effect of this difference was not great, however. The substantial predominance of treatment costs over augmentation costs in Table 13 gave reason to the similarity of total dollar and energy response surfaces. Except for the units (direct and primary joules), Figures 24 (a) and (b) likewise revealed like-shaped response surfaces.

An energy-efficient expansion path for DO control can be derived as were the dollar-efficient paths of Figure 22. This step was bypassed because of the similarity of the energy surfaces, Figure 24, to the dollar surface of

84
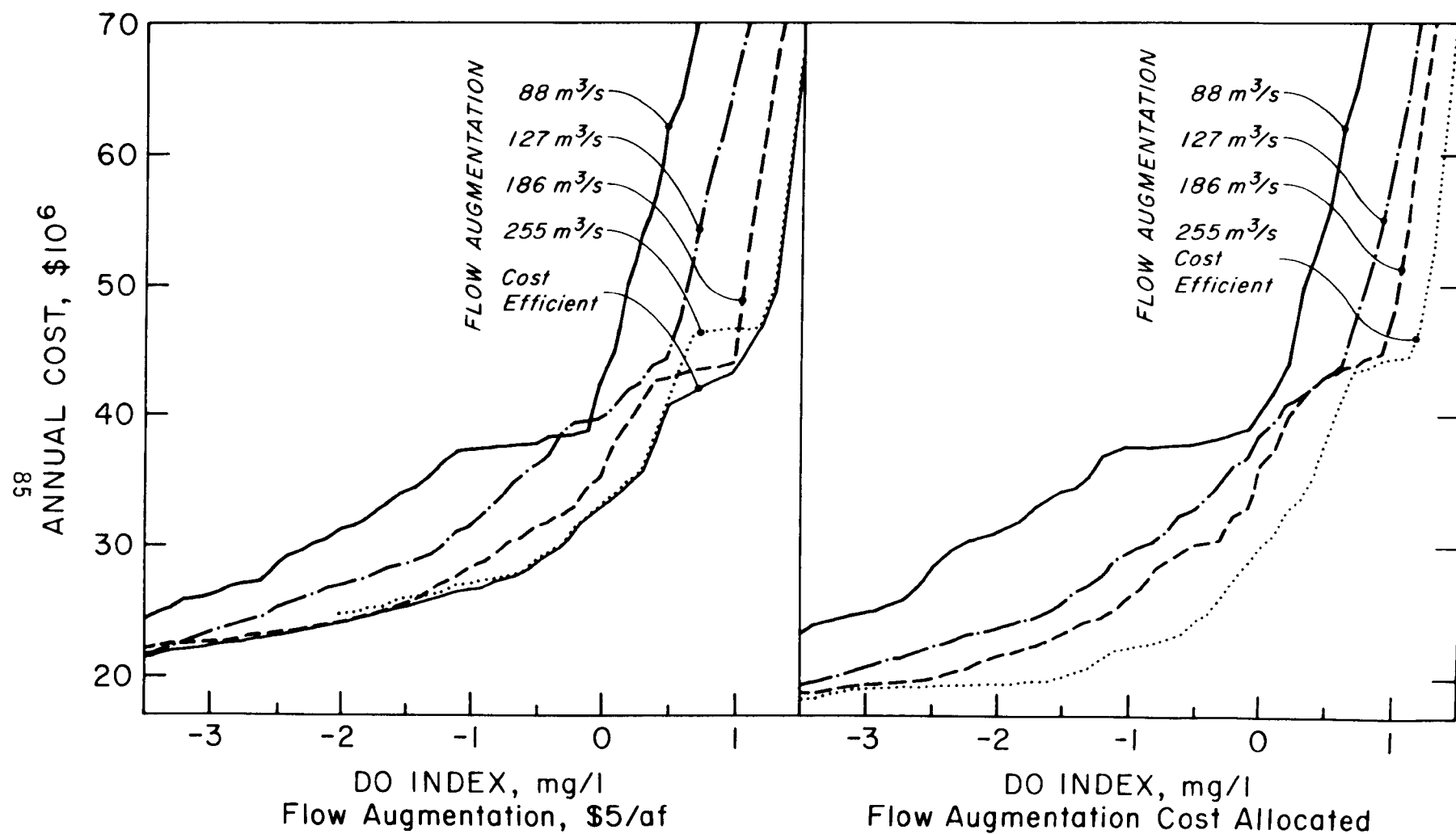
Figure 23. Annual cost versus DO index, flow augmentation (a) $5/af and (b) cost allocated.

TABLE 15. SUMMARY OF TREATMENT COSTS

Treatment level	$ x 10⁶, 1973			Direct energy, TJ			Primary energy, TJ		
	Capital	OMR annual	Total annual	Capital	OMR annual	Total annual	Capital	OMR annual	Total annual
A	154.72	4.41	16.14	1928	218	282	7324	391	669
B	174.96	5.30	19.41	2127	249	323	8508	463	800
C	233.65	7.28	27.57	2702	328	431	11940	628	1137
D	248.33	8.16	30.11	2846	363	473	12799	701	1253
E	303.62	9.29	35.64	3477	415	550	15661	800	1476
F	312.66	10.31	37.45	3566	467	606	16190	891	1593
G	317.10	10.67	38.33	3609	479	620	16449	919	1635
H	*	*	100.	*	*	1600	*	*	4000

* Not estimated.

TABLE 16. TREATMENT, AUGMENTATION, AND TOTAL
ANNUAL DIRECT ENERGY COSTS
(TJ)

Mean August discharge m^3/s	Treatment level							
	A	B	C	D	E	F	G	H
255	282	323	431	473	550	606	620	
	47	55	76	77	82	84	113	
	329	378	507	550	632	690	733	1600
186	282	323	431	473	550	606	620	
	22	40	34	37	54	53	99	
	304	363	465	510	604	659	719	1600
127	282	323	431	473	550	606	620	
	7	16	25	24	10	4	57	
	289	339	456	497	560	610	677	1600
88	282	323	431	473	550	606	620	
	0	0	0	0	0	0	0	
	282	323	431	473	550	606	620	1600

TABLE 17. TREATMENT, AUGMENTATION, AND TOTAL
ANNUAL PRIMARY ENERGY COSTS
(TJ)

Mean August discharge m^3/s	Treatment level							
	A	B	C	D	E	F	G	H
255	669	800	1137	1253	1476	1593	1635	
	149	172	238	241	257	262	359	
	818	972	1375	1494	1733	1855	1994	4000
186	669	800	1137	1253	1476	1593	1635	
	71	126	109	120	174	169	315	
	740	926	1246	1373	1650	1762	1950	4000
127	669	800	1137	1253	1476	1593	1635	
	22	51	81	75	30	13	181	
	691	851	1218	1328	1506	1606	1816	4000
88	669	800	1137	1253	1476	1593	1635	
	0	0	0	0	0	0	0	
	669	800	1137	1253	1476	1593	1635	4000
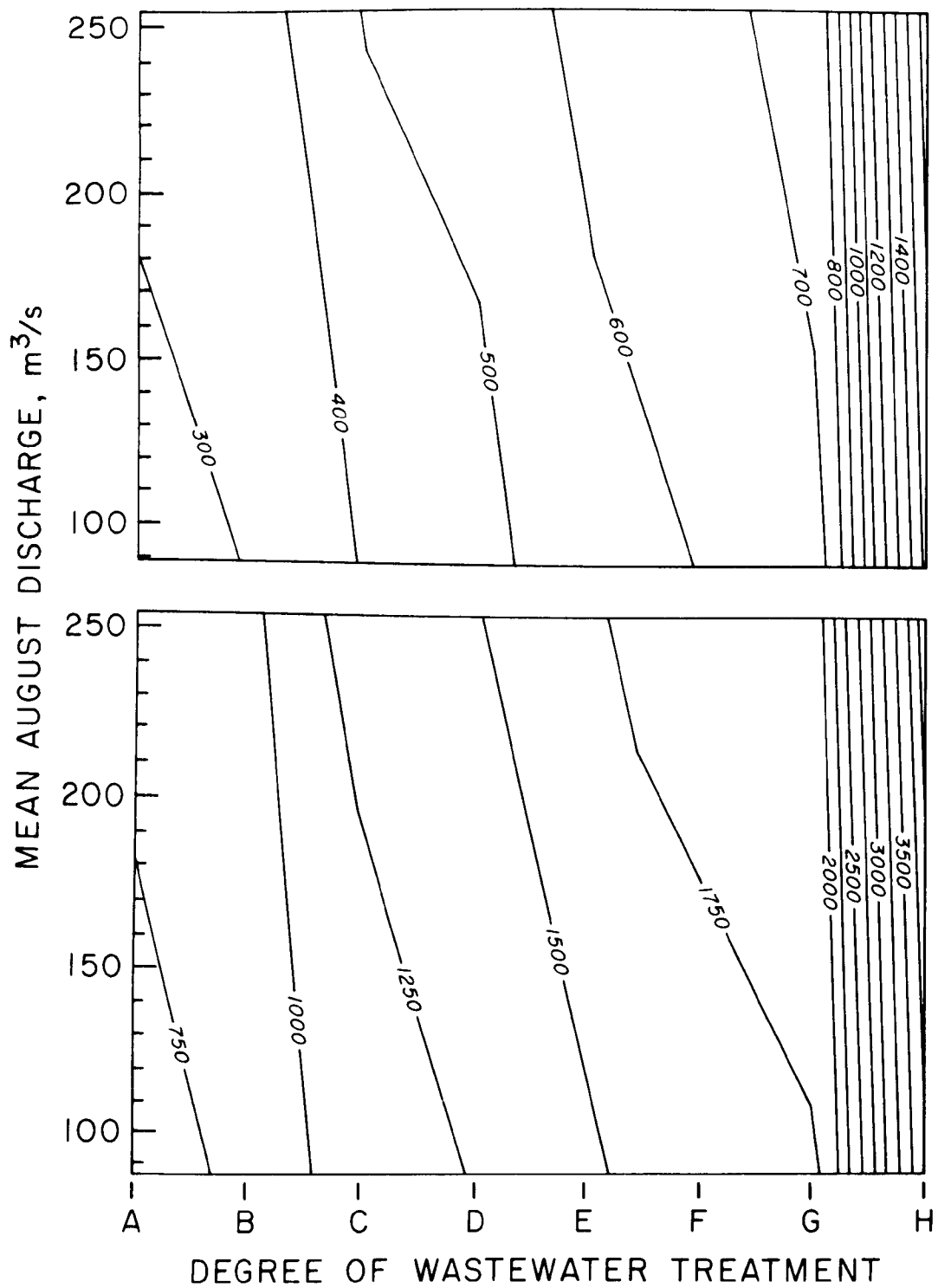
Figure 24. Annual (a) direct and (b) primary energy cost of water quality control response surfaces, TJ.

Figures 20(a) and (b). The energy contours were intermediate in slope between those where water is free and where it is valued at $5/af. Decisions based on energy alone will thus be like those based on dollars alone if water is in that price range. The energy-efficient combinations of flow and treatment lie between the $0 and $5/af paths of Figure 22.

SUMMARY

To bring together environmental, economic, and energy analysis of Willamette pollution control strategies, a 4 x 8 matrix of augmentation and wastewater treatment levels was developed. Augmentation varied from none to a level approximately 70 percent above that of the study year 1973. Point source treatment level varied from minimal to "complete" with emphasis given to degrees near conventional secondary technology.

For fixed levels of augmentation and treatment, the resulting river DO was simulated and indexed. Using the DO index for cost allocation, or simply assigning a unit price to flow augmentation, total costs for water quality treatment-flow strategy were estimated in dollars, and direct and primary energy. Results were converted into response surfaces, providing interpolated DO, dollar, and joule estimations for strategies other than those defined in the initial matrix.

The DO index and dollar response surfaces were used to develop cost-efficient steps of a strategy seeking improved DO. If augmentation were valued at a low unit price or cost allocated, augmentation should be maximized before increased secondary treatment facilities are purchased. If flow were highly valued for uses competitive with low flow augmentation (not now the case, but a possibility in the future), there would be justification in reduced flow maintenance in favor of increased treatment of pollutant loadings.

Whatever the means of augmentation pricing and whatever the mix of flow and treatment, the cost per incremental gain of DO begins to rise rapidly in the vicinity of 1973 treatment levels. This is in part due to the exponential costs of advanced wastewater treatment technology and in part due to the saturation limit of DO.

89

SECTION X

DISCUSSION

In the preceding section the analysis was drawn together in a graphical manner; this section deals with interpretation of that analysis. In this interpretation, the economic and energy consequences of DO quality protection are shown in a larger perspective. Discussion focuses on three issues. In what latitude can the modeled results be accepted? What do such results have to say about on-going efforts for Willamette water quality control? How does the cleanup satisfy the State environmental, economic, and energy policies?

VALIDITY OF ANALYTIC RESULTS

The modeled environmental, economic, and energy consequences for alternatives of water pollution control strategy are reasonable and informative. They may, however, be hastily interpreted in an unreasonable and misleading manner. Discussion in Sections V, VI and VII centered on the necessities of model selection suitable to the problem at hand and model employment compatible with assumptions and limits. At this point these items are reviewed. Each has bearing on the credibility that can be assigned to the modeling output.

The Study Period

August 1973 provided a base period in which water quality strategies could be compared. This period is well documented, marks significant restoration of a river, and illustrates the role of low flow augmentation for water quality control. Conclusions concerning water quality control for 1973 may be in part transferable to decision making in subsequent years if late summer streamflows are low, if waste production is not too different from that of 1973, if treatment technology is similar, and if the objective of environmental management is essentially one of mitigating DO problems of the lower Willamette during summers of low flow years.

DO Simulation

If the water quality model of this study is improper, subsequent error would be passed along into the cost allocation procedures. As the profiles of DO do appear to be satisfactory for periods of summer low flow in which the waste discharges are approximately of a secondary quality, such an error does not seem to occur. However, some treatment levels substantially below or above secondary quality were investigated; the accuracy of the DO predictions are unknown. (The DO profiles even at these extremes, however, seem to be reasonably consistent with historical records and conceptual projections). The environmental model is useful, but not substantiated outside of its assumed range. DO simulation in the near 1973 range can be assumed to be within

90

5 percent of true Willamette DO. DO simulation at the extreme treatment levels may be 10 or 15 percent in error.

Cost Estimation

Because inflation of the 1970's has rapidly altered cost data, the cost models developed in Section VII are only valid for 1973. Even within 1973, the models do not express the variation of prices for projects of the same size. The best information that the cost models yield deals with total sums over the entire Basin.

In the same manner that additional latitude should be given to DO predictions for treatments far from secondary, broader variability should be associated with cost estimates for treatment technologies significantly different than those commonly in use in 1973. In Figure 19, the dollar response surface slopes may be a little steeper or flatter at the sides. This, however, is a fortunate place to find a possible poor estimation. Because reasonable strategies for the 1970's do not include such low or very high degrees of waste treatment, costs associated with such treatment levels are not overly critical for decision analysis.

The allocation of reservoir costs is based upon the hypothesis that if summertime DO levels were not improved by flow augmentation, DO would be improved by treatment plant construction and operation. Additionally, the point source treatment would be directed toward management of infrequent summertime conditions, but would entail plant upgrading that would be employed throughout the year. Thus, alternative costs to augmentation are weighed heavily. This weight is the consequence of typical pollution control legislation imposing plant-type technical solutions and achievable quality discharge standards.

Energy Estimation

I/O energy estimates carry along errors of economic modeling and in the case of flow augmentation, of DO simulation. Thus energy impact is the least accurately modeled consequence of water pollution control.

The Input/Output energy model is an expression developed from aggregated data. I/O results are generally considered to be within 50 percent of actual case by case values (79). The more accurate uses of the I/O energy model deal with broad economic activities, defined by distinct I/O sectors. Water pollution control is not well partitioned by such general sectors. Therefore, even the 50 percent accuracy estimate may not be broad enough.

For general regional study, however, I/O energy estimates are of more value than such error allowance might indicate. Differences in direct energy intensity (Table 9) are both intuitively reasonable and roughly substantiated by regional survey data (3). Primary energy intensities are broadly derived from the national economy and thus should be a good estimate of mean energy-dollar relationships.

The I/O limitations and the subjectivity of sector assignments brought forth in Section VIII preclude I/O energy study outside of a system where

economic steady state is approximately maintained and where data exist on interindustrial transactions. Like all models, I/O cannot reveal truly new information, but rather provides additional perception into what is already identified.

In this study where investigation deals with a well-documented, short-term base period, results appear reasonable for regional analysis of energy differences between water pollution control alternatives where direct and primary energies define the scope of energy planning.

IMPLICATIONS FOR WILLAMETTE POLLUTION CONTROL

Pollution Control Standards

The selection of waste water treatment levels for the Basin (Table 10) reflects the DEQ's emphasis on achieving high secondary quality of discharges. Issues of nitrification are not pursued with the vigor applied to suspended solids. The flat gradient in the central section of Figure 18, the DO response surface, reveals that DO gains do indeed decelerate as wastewater treatment is directed towards goals other than dissolved oxygen quality.

Dissolved oxygen standards (5 mg/l in the tidal reach, 6 mg/l in the Newberg Pool, 7 mg/l Newberg to Salem, and 8 mg/l above Salem) were not met only in the Newberg area in 1973. Significantly, the lower standard at Portland was achieved. If the standards were modified, the rationale of the stairstep values should be examined. In reaches where rapid nitrification is expected, DO limits might perhaps be reduced by as much as 0.5 mg/l. In the lower Willamette, where deoxygenation rates are low, DO limits might be increased, by as much as 1 mg/l, to better reflect what pollution control can effectively attain.

The cost versus DO index curves (Figure 23) indicate that future DO improvement may become less attractive as an environmental goal. By either of two pricing schemes for augmentation, pollution control costs rise with DO gains. Of significance in these cost curves is the domain of DO indices where costs begin to soar. The upturn generally begins in the -1 to 0 interval. From both the dollar and energy perspective, diseconomies of scales are substantial for continued DO improvement. Pollution control standards should strive to maintain a DO to protect aquatic life, but the standard established is a reflection of public priorities, not precise calculation.

A Unit Price for Low Flow Augmentation

Because cost allocation is not undertaken every time a decision must be made concerning low-flow reservoir releases, a general estimator for the economic value of augmentation is of use to the planner. In Appendix D, a $5/af price is assigned to instream augmentation as irrigation benefits foregone. The cost allocation of reservoir costs, however, allows this estimation to be improved.

If the allocated cost response surface in Figure 19 is compared with surfaces derived from fixed charges in Figures 20 and 21, the allocation outcome

most closely resembles the response surface in Figure 20(b), the $5/af value. This provides some substantiation of the $5/af estimate. The allocated surface, however, is somewhat less deflected by augmentation than is the Figure 20(b), $5/af value. A $3/af unit price might be a somewhat better allocated valuation for flow augmentation. This would assume less net gains resulting from expanded irrigation (a proper correction, see Appendix D) and allow a cost allocation for reservoirs more in conformity with original authorization. This unit price for augmentation assumes that water quality is judged by low-flow summertime DO levels in the lower Willamette (return period, 25 years). The price is appropriate only to drawdown from existing reservoirs.

Evaluation of 1973 DO Control

At $3/af, the expansion paths of Figure 22 reveal that the cost-effective approach to DO control is one in which low flow augmentation is generally maximized. It appears that if flow were valued at approximately $8/af, the actual 1973 treatment-flow mix (D, 186 m³/s) would lie on an expansion path and thus be efficient. The 1973 management thus overvalues water used to maintain water quality. The Willamette, however, is not regulated solely for dollar efficiency. Low flow level has been roughly fixed whereas treatment technology has been continuously stepped up. Augmenting flow to the 186 m³/s level and adding treatment necessary for DO is a reasonable strategy for environmental control. The reservoir release, a tactic politically difficult to alter, is set at an intermediate value and then river DO is tuned with the easier to modify variables, the treatment plants.

Pertinence to Future Regulation

The expansion paths of Figure 22 give a degree of economic justification to the DEQ's contention that augmentation may be curtailed in the future. It does appear that low flow could be efficiently reduced if raw waste production were held at 1973 levels (this might assume moderate economic development balanced with an increased conservation ethic), and if treatment were upgraded to a high secondary (level G) quality. It appears, however, that if wastewater treatment needs advance beyond this level, flow at any reasonable price would be best used to dilute wastes in the river.

The 1973 level of augmentation (186 m³/s) seems again to be one of moderation. Until future loadings, constraints on waste treatment, DO targets, and irrigation benefits are more certainly foreseen, there is little reason to substantially alter the reservoir release curves and increase possible future corrections.

Energy Considerations

A final implication for pollution control results from the energy perspective. The question arises whether decisions drawn on a direct or primary energy basis will be different than those based on dollars. In the previous section, both direct and primary energy costs were represented over the plane of treatment-augmentation possibilities by response surfaces similar to the dollar surfaces for either case where flow was cost allocated or priced $3/af. If so priced, the 186 m³/s release was shown to be low. Thus this level of

flow is low also in energy terms, both direct and primary. This sort of confirmation should not be interpreted as an independent check on environmental strategy. The dollar-to-energy coefficients that I/O develops are generally similar enough to each other (Table 9) that the conclusions drawn from this type of energy considerations are not likely to be substantially unlike those derived from dollars. Because reservoir dollars affect energy somewhat less than treatment dollars (Table 9), energy-efficient decisions should call for somewhat more augmentation at given treatment than would cost-efficient decisions if any differences should arise in the selection of environmental strategy.

Given the very approximate nature of I/O coefficients and the dependency of I/O conclusions upon dollar cost figures, I/O energy study for Willamette regulation should be seen as potentially informative, but should not be expected to greatly broaden more conventional economic analysis.

IMPLICATIONS FOR BASIN POLICY

The response surfaces and expansion paths can serve as a guide for efficient decision making, but they imply nothing about where development should cease. Just because it may be prudent to add a little more flow augmentation before a little more wastewater treatment, this is not a proof that either should be added. The extent of water pollution control must be tied to the objectives of the system for which water pollution control is just one activity. Those objectives direct policy. As emphasized in Section V, such policy may be viewed from many perspectives, among them environmental, economic, and energy. In this section, the analytic interpretation of Willamette pollution control strategy is put into such perspectives.

Environmental Policies

Upgrading Willamette DO has been a prime objective of water management in the Basin. The DEQ's Water Quality Management Plan specifies DO river standards that were substantially met in 1973 (10, 27). Post-1973 regulation is roughly mapped as a shift to the lower right on the treatment-flow possibility planes (Figures 18 to 24). If the DO index would remain near 0, treatment plants would continue to be upgraded, and augmentation abstracted for irrigation. Such a direction is compatible with the official plan since wastewaters are treated to protect other legitimate river uses. The environment, quantified by DO index, would not be degraded.

Economic Policies

The last section indicated that, given near-secondary wastewater treatment, a $25 to $45 million per year pollution control cost range existed among feasible pollution control strategies. The actual strategy evolved by 1973, annually cost $33 million ((D, 186) in Table 13 or Figure 19). Is this expense reasonably consistent with the Basin's economic goals?

Approximately $12 million of the Basin's annual pollution control expenses were incurred industrially (Treatment Level D in Appendix H). The larger portion of these costs are born by the pulp and paper industry. If the entire

94

$12 million annually for water quality control were divided by the Basin's forest product payroll of $500 million, a low approximation of value added to forest goods, the forest industry appears to spend about 2 percent of its value added for Willamette quality protection. The Basin's agriculture, the other regional economic mainstay, spends much less.

The Basin's aesthetic environment supports substantial sporting economic activity and draws smaller industries to the region. Regional economic advancement brought on by this spinoff probably outweighs a $12 million annual environmental burden placed on the resource industries.

If the annual cost of water quality control were divided among the Basin's residents, a per capita charge of $20 would result. This corresponds to somewhat less than one-half of one percent of mean personal income. Because both reservoirs and wastewater treatment plants are federally subsidized, the direct per capita price is even smaller. Given the environmental enhancement, most Oregonians do not think that the price is excessive.

Of the $33 million annual water pollution control cost, slightly over $6 million is spent annually for fixed or independent pollution control tactics, those activities of wastewater treatment wherein the discharge quality is not reflected in the river. The remaining $27 million is the fund distributed to incremental quality-achieving alternatives. Of this, $3 million, if cost allocated, is used for reservoirs and $12 million each are spent by municipalities and industries. In that these charges are well distributed over the Basin, this spending reflects the State policy of balanced development.

The Basin's economic growth might be curtailed if industries were forced to assume a larger part of the total cost. Economic activity might be accelerated if subsidized pollution control from reservoirs and municipal plants were used to alleviate the industrial burden.

The 1973 level of augmentation and wastewater treatment is reasonably consistent with the State economic policy, its emphasis on orderly, planned and balanced growth. Significantly, however, a DO target upgraded 1 mg/l over that of 1973 could double pollution control costs and potentially disrupt economic development.

Energy Policies

If the direct energy used for pollution control (510 TJ, Table 16) is compared to Basin energy use for 1973 (350,000 TJ, Figure 13, population 1,500,000), between 0.1 and 0.2 percent of the Basin's power was consumed for water quality management. This value is in agreement with national estimates of 0.1 to 0.3 percent for electricity and petroleum required for water pollution control (83). That energy requirement could double with advances in treatment level (700 or 800 TJ for Level G, 1600 for Level H, Figure 24).

If the State's energy budget were to continuously increase at several percent per year, the energy needs for pollution control could probably be satisfactorily absorbed. This indeed reflects State and energy industry forecasts. Oregon may, however, find its energy sources curtailed sooner than an-

ticipated. As this occurs, energy expenditures for pollution control will be more and more determined by the alternative uses in which that power might be used.

Oregon's energy policies call for diverse, permanently sustainable energy resources, conservatively used to meet basic human needs and preserve environmental quality. A logical consequence of an energy policy utilizing renewable energies would be environmental strategies drawing upon the assimilative capacity of nature. For Willamette DO maintenance, joules spent for reservoirs generally accomplish more than do joules spent in wastewater treatment, shown by an expansion path across the top of Figure 24(a). If augmentation were maximized and raw waste production fixed, pollution control activity might reduce 10 or 20 percent from its energy needs with negligible DO effects.

The energy perspective affords checks on pollution control tactics. One such check is carried out in Appendix I. The energy required to build and operate a reservoir is compared with the energy hydraulically produced. It appears that if power is generated, a 17:1 return is realized on energy invested. A similar calculation using generalized national figures indicated the ratio might be 100:1 (84). By either accounting, hydroelectric generation appears to be net energy productive, thus in conformity to policy objectives.

An Alternative Perspective

As illustrated in Section V, energy flows into and within a system provide a basis for understanding the nature of that system. The 1973 costs for Willamette pollution control were approximately $33 million, 510 direct TJ, and 1373 primary TJ (Tables 13, 15 and 17). If these dollars are translated to calorie equivalent at $1 equal to 25,000 Calories as suggested by Odum, these three measures of dollars, direct energy and primary energy are 0.83×10^{12}, 0.12×10^{12} and 0.33×10^{12} Cal/yr (51). Since the primary figure includes energy directly sold to pollution control, the difference, 0.21×10^{12} Cal/yr, represents the fossil energy consumed elsewhere and embodied in pollution control inputs. The primary energy total subtracted from the dollar energy total, 0.50×10^{12} Cal/yr, represents energy consumed in the Basin's household sector.

In Figure 14, the 0.12×10^{12} direct Cal/yr is a portion of the 87×10^{12} Cal/yr, the Basin's direct energy input. Of the 34×10^{12} Cal of imports and 45×10^{12} Cal of intraindustrial consumption, 0.21×10^{12} Cal were required for pollution control. Of the 118×10^{12} Cal ultimately consumed by the Basin's population, 0.50×10^{12} Cal were derived from water quality management.

Whereas the largest portion of water quality regulation energy is eventually consumed in the Basin's households (0.50×10^{12} of 0.83×10^{12} Cal/yr), this energy is largely an economic flow that would likely continue with or without pollution control investment. If the Valley opted for a very low quality river, the dollars would have been spent for something else. The environmental planner may be able to save the public money, but he cannot halt the spending of these savings for other goals.

The use of 0.12 x 10^{12} direct and 0.21 x 10^{12} embodied Cal/yr associated with water quality control is reasonably responsive to planning. If spent, this energy results in an overall environmental gain. If not spent, this energy might be removed from Basin imports. This last alternative is perhaps the most significant to the Basin's overall planning. The Willamette Basin is currently subsidized with imported primary energy. As the world's energy stocks dwindle, this subsidy cannot be maintained. Cutbacks in direct energy imports will occur, and energy intensive goods will be harder to obtain. Energy in both forms will be sought with increased vigor by all segments of the economy, only one of which is pollution control. It is most improbable that pollution control can garner enough energy inflows to continuously upgrade water quality (moves to the right on Figures 20(a) and (b)). It is not guaranteed under conditions of energy shortages that water pollution control can even maintain its current energy expenditures.

This paper analytically deals in the short range. A broader integrated perspective shows the differences inherent between short and long run answers. Short run policy and analysis needs to be first internally reconciled. Treatment plant investment should be coordinated with reservoir operation. Then, as understanding of the total system increases, short run perspective might as a whole be better directed toward long run solutions.

SUMMARY

This report deals with alternatives not radically different from pollution control management of 1973. The environmental, economic, and energy models selected are suitable for that base period. Even with such specification, the economic and energy expressions yield only approximations of impact. The established level of low flow augmentation appears to be of reasonable economic efficiency, given uncertainty about the value of water and demands in the future. If DO were upgraded to yet higher levels, or if energy efficiency were considered, reason would exist for selecting an environmental strategy weighted toward additional flow maintenance.

The water quality strategy of 1973 is harmonious with the substance of State environmental and economic policies. The reliance on imported energy to accomplish such regulation is not in keeping with Oregon's energy policy. It appears that the three policy perspectives have yet to be reconciled.

From a broader viewpoint, the 1973 mode of water quality control is at odds with the Basin's long range energy-based outlook. If the imported energy subsidy to Oregon's economy should dwindle, energy-cheap strategies for environmental management, such as low flow augmentation, may have to be implemented and energy-intensive alternatives reduced.

REFERENCES

1. Gleeson, G. W.   The Return of a River: The Willamette River, Oregon.
    Water Resources Research Institute.   Oregon State University.
    Corvallis, OR.   WRRI-13.   1972.   103 p.

2. Britton, J. E.   A History of Water Pollution Control in the
    Willamette Basin, Oregon.   US Public Health Service.   Portland,
    OR.   Working Paper No. 56.   July 1965.   56 p.

3. Huff, E. S., P. C. Klingeman, H. H. Stoevener, and H. F. Horton.
    Restoring the Willamette River: Costs and Impacts of Water Quality
    Control.   Oregon State University.   Corvallis, OR.   EPA-600/5-76-005.
    US Environmental Protection Agency.   September 1976.   163 p.

4. Baldwin, E. M.   Geology of Oregon.   2nd Edition.   Eugene, University
    of Oregon Cooperative Book Store, 1964.   p. 1-76.

5. Willamette Basin Comprehensive Study of Water and Related Land
    Resources: Appendix B, Hydrology.   Willamette Basin Task Force.
    Pacific Northwest River Basins Commission.   Vancouver, WA.   1969.

6. Large Rivers of the United States.   US Geological Survey.
    Washington, DC.   Circular 44.   May 1949.

7. Rickert, D.A., W. G. Hines, and S. W. McKenzie.   Methodology for
    River-Quality Assessment with Application to the Willamette River
    Basin, Oregon.   US Geological Survey.   Washington, DC.   Circular
    715-M.   1976.   55 p.

8. Water Resource Data for Oregon.   Part 1.   Surface Water Records.
    US Geological Survey.   Washington, DC.   Annual.

9. Willamette Basin Water Quality Control Plan (Draft).   Department
    of Environmental Quality.   Portland, OR.   Unpublished.   1973.

10. Proposed Water Quality Management Plan, Willamette River Basin.
    Text and Appendices.   Department of Environmental Quality.
    Portland, OR.   1976.

11. Columbia River Water Management Report.   Columbia River Water
    Management Group.   Portland, OR.   Annual

12. Surface Water Supply of the United States, Pacific Slope Basins in Oregon and Lower Columbia River Basin. US Geological Survey. Washington, DC. Annual.

13. Oregon Blue Book: 1977-1978. Secretary of State. Salem, OR. 1977. p. 219-222.

14. Willamette Basin Comprehensive Study of Water and Related Land Resources: Appendix C, Economic Base. Willamette Basin Task Force. Pacific Northwest River Basins Commission.

15. Columbia-North Pacific Region Comprehensive Framework Study. Appendix IX: Irrigation. Pacific Northwest River Basins Commission. Vancouver, WA. February 1971. p. 247-267.

16. Willamette Basin Comprehensive Study of Water and Related Land Resources: Appendix F: Irrigation. Willamette Basin Task Force. Pacific Northwest River Basins Commission. Vancouver, WA 1969.

17. Oregon's Long-Range Requirements for Water: Appendix II, Irrigation and Food Products Projections. State Water Resources Board. Salem, OR. June 1969. p. 5-19.

18. Water Resources Development by the US Army Corps of Engineers in Oregon. North Pacific Division. US Army Corps of Engineers. Portland, OR. Annual.

19. Waterborne Commerce of the United States. Part 4: Waterways and Harbors. Pacific Coast, Alaska and Hawaii. US Army Corps of Engineers. Vicksburg, MS. Annual.

20. Hydroelectric Plant Construction Cost and Annual Production Expenses. Seventeenth Annual Supplement. Federal Power Commission. Washington, DC. May 1976. p. 57-105.

21. Willamette Basin Comprehensive Study of Water and Related Land Resources: Main Report. Willamette Basin Task Force. Pacific Northwest River Basins Commission. Vancouver, WA. 1969.

22. Annual Report of the Chief of Engineers on Civil Works Activities. Volume II. Office of the Chief of Engineers, US Army Corps of Engineers. Washington, DC. Annual.

23. Annual Report. Oregon State Parks Division. State Highway Department. Salem, OR. Annual.

24. Willamette Basin Comprehensive Study of Water and Related Land Resources: Appendix K, Recreation. Willamette Basin Task Force. Pacific North West River Basins Commission. Vancouver, WA. 1969.

25. Water Pollution Control in Oregon: Annual Report. Oregon State Sanitary Authority. Portland, OR. 1950-1965.

26. Biennial Report. Oregon State Sanitary Authority. Portland, OR. Numbers 1-13. 1940-1964.

27. Water Quality Control in Oregon. Oregon Department of Environmental Quality. Portland, OR. 1970, 1975.

28. Velz, C.J. Applied Stream Sanitation. New York, Wiley-Interscience, 1970. 619 p.

29. Hines, W.G., S. W. McKenzie, and D. A. Rickert. Dissolved Oxygen Regime of the Willamette River, Oregon under Conditions of Basinwide Secondary Treatment. US Geological Survey. Washington, DC. In publication.

30. Hines, W. G. US Geological Survey. Portland, OR. Personal Communication.

31. Loy, W. G., S. Allan, C. P. Patton, and R. D. Plank. Atlas of Oregon. University of Oregon. Eugene, OR. 1976. 215 p.

32. Walker, W. R., and W. E. Cox. Legal Aspects of Storage for Water Quality Improvement. Journal of the Water Pollution Control Federation. Vol. 43, No. 12: 2394-2401, December 1971.

33. Walker, W. R., and W. E. Cox. Legal Aspects of Water Supply and Water Quality Storage. Virginia Polytechnic Institute. Blacksburg, VA. Bulletin 37. August 1970. 235 p.

34. DeWeerdt, J. L., P. M. Glick (ed.). A Summary-Digest of the Federal Water Laws and Programs. National Water Commission. US Government Printing Office. Washington, DC. 1973. 205 p.

35. State Water Resources Board of Oregon. Lower Willamette River Basin Program. October 8, 1976. Middle Willamette River Basin Program. June 22, 1964.

36. State of Oregon. Oregon Revised Statutes. 468.710. 1974.

37. Straub, R.W., Governor of Oregon. Letter of October 14, 1977.

38. Industrial Forestry Association. Corvallis Gazette-Times. Corvallis, OR. 69(191):2. December 9, 1976.

39. Miles, S. D. Extension Economist. Oregon State University. Corvallis, OR. Personal Communication. January 14, 1977.

40. 1975-1976 Biennial Report. Oregon Department of Fish and Wildlife. Portland, OR. December, 1976. 56 p.

41. Fitch, J. B., and J. E. Schefter. Income Distribution Patterns in Oregon: A Comparison of Oregon Counties through Time. Oregon State University. Corvallis, OR. November 1974. 28 p.

42. Population and Household Trends in Washington, Oregon and Northern Idaho 1970-1985. Pacific Northwest Bell. Seattle, WA. 1972.

43. Holden, A. G., and W. B. Shepard. Migration and Oregon -- 1970: Patterns and Implications. Oregon State University. Corvallis, OR. May 1974. 112 p.

44. State of Oregon. Oregon Revised Statutes. 184.003. 1973.

45. Future Energy Options for Oregon. Oregon Department of Energy. Salem, OR. December 1976.

46. Report to Governor Bob Straub. Task Force on Energy Conservation. State of Oregon. Salem, OR. November 24, 1975.

47. Muckleston, D. W. Department of Geography. Oregon State University. Corvallis, OR. Personal Communication.

48. Report on the US Columbia River Power System. Bonneville Power Administration. Portland, OR. Annual.

49. McCall, T. In: Transcript of Fourth Public Hearing, Seattle, Boise, Portland, and Anchorage, Project Independence, Federal Energy Administration. Washington, DC. September 5-7, 1974. p. 715-717.

50. State of Oregon. Oregon Revised Statutes. 469.010. 1975.

51. Odum, H. T. and E. C. Odum. Energy Basis for Man and Nature. New York, McGraw-Hill Book Company, 1976. 297 p.

52. Weinberg, G. M. An Introduction to General Systems Thinking. New York. Wiley. 1975. 279 p.

53. Friedman, J. M. Efficiency in Water Quality Control for the Willamette River. Annals of Regional Science. IX (1): 45-55, March 1975.

54. Liebman, J. C., and W. R. Lynn. The Optimal Allocation of Stream Dissolved Oxygen. Water Resources Research. 2 (3): 581-591. Third Quarter 1966.

55. Worley, J. L. A System Analysis Method for Water Quality Management bh Flow Augmentation. Masters Thesis. Civil Engineering, Oregon State University. Corvallis, OR. June 1963. 137 p.

56. Waddell, W. W. User's Manual for EXPLORE-I and PIONEER-I.
     Battelle Northwest. Richland, WA. April 1974. 83 p.

57. An Analysis of the Waste Load Assimilation Capacity of the
     Willamette River Basin. Parts I-III. Battelle Northwest,
     Richland, WA. December 1973, April 1974.

58. Larson, D. W. Upstream Reservoirs as Important Sources of
     Planktonic Algae and Nutrients Influencing the Eutrophication
     of Lower Impoundments in the Willamette River Basin, Oregon.
     Synopsis. Oregon Department of Environmental Quality.
     Portland, OR. March 1974. 38 p.

59. Rickert, D. A. , V. C. Kennedy, S. W. McKenzie, and W. G. Hines.
     A Synoptic Survey of Trace Metals in Bottom Sediments of the
     Willamette River, Oregon. US Geological Survey. Washington,
     DC. Circular 715-F. 1977. 27 p.

60. Rickert, D. A., R. R. Peterson, S. W. McKenzie, W. G. Hines,
     and S. A. Wille. Algal Conditions and the Potential for Future
     Algal Problems in the Willamette River, Oregon. US Geological
     Survey. Washington, D. C. Circular 715-G. 1977. 39 p.

61. Shearman, J. O. Reservoir-System Model for the Willamette River
     Basin, Oregon. US Geological Survey. Washington, DC.
     Circular 715-H. 1976. 22 p.

62. Engineering News Record. McGraw-Hill. March 24, 1977. p. 67.

63. Estimating the Costs of Wastewater Treatment Facilities.
     Culp, Wesner, Culp. El Dorado Hills, CA. March 1974. 37 p.

64. Michel, R. L. Costs and Manpower for Municipal Wastewater
     Treatment Plant Operation and Maintenance, 1965-1968. Journal
     of the Water Pollution Control Federation. 42(11):1883-1910.
     November 1970.

65. Di Gregorio, D. Cost of Wastewater Treatment Processes. Feder-
     al Water Pollution Control Administration. Cincinnati, OH.
     December 1968. 53 p.

66. Smith, R., and R. G. Eilers. Cost to the Con sumer for Collection
     and Treatment of Wastewater. Environmental Protection Agency.
     Cincinnati, OH. EPA 17090--07/70. July 1970. 86 p.

67. Klemetson, S. L., and W. J. Grenney. Physical and Economic Para-
     meters for Planning Regional Wastewater Treatment Systems.
     Journal of the Water Pollution Control Federation. 48(12):
     2690-2699, December 1976.

68. Davis, H. C. Economic Evaluation of Water. Part V. Multi-regional Input-Output Techniques and Western Water Resources Development. Water Resources Center. University of California. Berkeley, CA. Contribution No. 125. February 1968. 142 p.

69. Gray, S. L., and J. R. McKean. The Development of Water Multiplier Impacts from Input-Output Analysis: An Empirical Example from Boulder, Larimer, and Weld Counties, Colorado. Water Resources Research. 12 (2): 135-140, April 1976.

70. Leontief, W. W. Environmental Repercussions and the Economic Structure: An Input-Output Approach. The Review of Economics and Statistics. LII (3): 262-271, August 1970.

71. Herendeen, R. A. The Energy Cost of Goods and Services. Oak Ridge National Laboratory. Oak Ridge, TN. ORNL-NSF-EP-58. October 1973. 116 p.

72. Herendeen, R. A., and C. W. Bullard. Energy Cost of Goods and Services. Center for Advanced Computation. University of Illinois. Urbana, IL. CAC 140. November 1974.

73. Simpson, D. , and D. Smith. Direct Energy Use in the U. S. Economy, 1967. Center for Advanced Computation. University of Illinois. Urbana, IL. CAC 39. January 1975. 45 p.

74. Georgescu-Roegen, N. The Entropy Law and the Economic Process. Cambridge, Harvard University Press, 1971.

75. Herendeen, R. A. An Energy Input-Output Matrix for the United States, 1963: A User's Guide. Center for Advanced Computation. University of Illinois. Urbana, IL. CAC 69 March 1973. 99 p.

76. Bullard, C. W., and R. A. Herendeen. Energy Impact of Consumption Decisions. Center for Advanced Computation. University of Illinois. Urbana, IL. CAC 135. October 1974.

77. Calligan, C. C. Willamette Simulation Unit. Oregon State University. Personal Communiciation.

78. Allen, R. L., and D. A. Watson. The Structure of the Oregon Economy: An Input/Output Study. Bureau of Business and Economic Research. University of Oregon. Eugene, OR 1965. 35 p.

79. Herendeen, R. A. Center for Advanced Computation. University of Illinois. Personal Communication. February 1975.

80. Energy Use in the Contract Construction Industry. Tetra Tech. Arlington, VA. TT-A-412-75-011. February 18, 1975.

81. Dunnette, D. A. Effect of an Industrial Ammonia Discharge on the Willamette River. Department of Environmental Quality. Portland, OR. January 1977. 31 p.

82. Ferguson, C. E., and S. C. Maurice. Economic Analysis. Homewood, IL, Richard D. Irwin, 1970. p. 121-124.

83. Smallwood, D. S., and R. F. Weston. Industrial Energy Usage Considerations Associated With the Implementation of the Federal Water Pollution Control Act Amendments of 1972 (PL92-500). Roy F. Weston, Inc. (Presented at Energy and Environmental Quality. Chicago. May 10, 1974.) 17 p.

84. Roberts, E. B., and R. M. Hagan. Energy Requirements of Alternatives in Water Supply, Use, and Conservation: A Preliminary Report. California Water Resources Center. University of California. Davis, CA. Contribution No. 155. December 1975.

85. Harris, D. D. Travel Rates of Water for Selected Streams in the Willamette River Basin, Oregon. U.S. Geological Survey. Washington, DC. Atlas HA-273. 1968. 2 p.

86. Kramer, L. Letter. In: Better Data Collection and Planning is Needed to Justify Advanced Waste Treatment Construction, Report to the Congress by the Comptroller General of the United States. Washington, General Accounting Office December 21, 1976. p. 60-62

87. Miller, S. F. An Investigation of Alternative Methods of Valuing Irrigation Water. Ph.D. Thesis. Oregon State University. Corvallis, OR. 1965. p. 126-128.

88. Rockwood, D. M. North Pacific Division, U. S. Army Corps of Engineers. Portland, OR. Personal Communication. February 22, 1977.

89. Carson, W. D. Jr. An Investigation of the Determinants of Reservoir Recreation Use and Demand: The Effect of Water Surface Elevation. Hydrologic Engineering Center, Corps of Engineers. Davis, CA. Research Note No. 2. November 1972. 53 p.

90. James, L. D., and R. R. Lee. Economics of Water Resources Planning. New York, McGraw-Hill Book Company, 1971. p.527-540.

91. Loughlin, J. C. The Efficiency and Equity of Cost Allocation Methods for Multipurpose Water Projects. Water Resources Research. 13(1): 8-14, February 1977.

92. Input-Output Structure of the U. S. Economy: 1967. Volume 1 - Transactions Data for Detailed Industries, Volume 2 - Direct Requirements for Detailed Industries, Volume 3 - Total Requirements for Detailed Industries. Social and Economic Statistics Administration, Bureau of Economic Analysis. U. S. Department of Commerce. Washington, DC. 1974.

93. Report to the Congress by the National Commission on Water Quality. Government Printing Office. Washington, DC. March 18, 1976. 90 p.

GLOSSARY

af	– Acre-ft, 1233 m^3
BOD	– Biochemical Oxygen Demand
BOD_5	– Biochemical Oxygen Demand, 5 day
Btu	– British thermal unit, 1055 J
C	– Celsius
Cal	– Calorie, 4187 J
CBOD	– Carbonaceous BOD
cfs	– cubic ft per second, 0.0283 m^3/s
COD	– Chemical Oxygen Demand
DO	– Dissolved Oxygen
ft	– Feet, 0.3048 m
G	– Giga, 10^9
g	– Gram
J	– Joule
k	– Kilo, 10^3
l	– Liter
m	– Meter
M	– Mega, 10^6
mgd	– Million gallons per day, 0.04381 m^3/s
mg/l	– Milligrams per liter
NBOD	– Nitrogenous BOD
Rkm	– River kilometer
s	– Second
T	– Tera, 10^{12}
Wh	– Watt-hour, 3600 J

TABLE A-18. MUNICIPAL WASTEWATER TREATMENT PLANTS DISCHARGING TO WILLAMETTE, AUGUST 1973 (3, 9, 10)

Plant	Type*	Year built	Discharge, mgd 1973	Design	Receiving stream river kilometer
Albany	AS	1969	5.33	8.70	Willamette - 191.5
Aloha	ASEF	1965	1.20	4.00	Beaverton Cr. - 5.3
Banks	ASP	1967	.05	.14	W.Fk. Dairy Cr. - 16.1
Beaverton	TFEF	1970	1.90	1.60	Beaverton Cr. - 12.9
Canby	AS	1963	.34	.85	Willamette - 53.1
Carlton	TF	1955	.12	.30	N.Yamhill - 9.7
Cedar Hills	TF	1962	.92	1.30	Beaverton Cr. - 12.1
Central Linn Hi. School	ASP	1958	.01	.01	Spoon Cr. - 7.1
Century Meadows	ASP	1972	.04	.04	Willamette - 67.6
Chatnicka Heights	ASP	1964	.01	.04	Winslow Cr. - 7.2
Cornelius	TF	1959	.21	.25	Tualatin - 84.2
Corvallis	TF	1966	6.60	7.26	Willamette - 210.8
Corvallis Airport	L	1962	.01	.01	Cr. to Willamette - 222.0
Corvallis Mobile Home	ASP	1959	.02	.01	Oak Cr. - 2.6
Cottage Grove	TF	1967	.92	1.50	Coast Fork Willamette - 35.4
Country Squire	ASPL	1964	.02	.07	Muddy Cr. - 77.2
Creswell	L	1962	.12	.17	Camas Sw. - 8.0
Dallas	AS	1969	.70	2.00	Rickreall Cr. - 16.9
Dammasch Hospital	TF	1960	.11	.30	Corral Cr. - 1.6
Dayton	L	1965	.10	.10	Yamhill - 8.0
Dundee	L	1970	.06	.13	Willamette - 83.7
Eola Village	TF	1941	.08	.07	S.Yamhill - 24.1
Estacada	TF	1963	.12	.38	Clackamas - 38.0
Eugene	TF	1971	13.80	16.00	Willamette - 286.4
Fanno	AS	1969	3.15	3.00	Fanno Cr. - 13.4
Fir Cove Sanitation	ASP	1957	.00	.02	Coast Fork Willamette - 1.6
Gaston	ASP	1964	.04	.06	Tualatin - 103.8
Halsey	L	1969	.05	.10	Muddy Cr. - 37.0
Happy Valley Homes	ASP		.01	.01	Mitchell Cr. - 2.4
Harrisburg	TF	1967	.09	.25	Willamette - 259.0
Hillsboro	AS	1959	.91	1.25	Rock Creek - 0.0
Hillsboro Jr. Hi.	ASP	1963	.01	.01	Beaverton Cr. - 0.0
Hillsboro West	AS	1971	.86	2.00	Tualatin - 59.5
Hubbard	TF	1968	.10	.20	Mill Cr. - 8.5
Independence	L	1967	.30	.39	Ash Cr. - 2.1
Jefferson	L	1969	.10	.11	Santiam - 11.3
Lafayette	L	1964	.08	.10	Yamhill - 12.9
Laurelwood Academy	TF	1967	.04	.02	Hill Cr. - 9.7
Lebanon	TF	1958	.68	1.90	S. Santiam - 28.0
Lowell	TF	1949	.56	.26	Mid Fork Willamette - 29.8
Lowell Park	ASP	1960	.01	.01	Mid Fork Willamette - 27.2
Marylhurst	TF	1962	.62	.11	Willamette - 35.2
McMinnville	AS	1971	1.87	4.00	S. Fork Yamhill - 6.4
Metzger	AS	1966	1.50	2.50	Fanno Cr. - 7.9
Millersburg School	L	1966	.01	.01	Crooks Cr. - 10.0
Milwaukie	AS	1962	1.70	2.00	Willamette - 29.0
Molalla	TF	1955	.20	.40	Bear Cr. - 0.8
Monmouth	L	1964	.50	.70	Ash Cr. - 4.2

Plant	Type*	Year built	Discharge, mgd 1973	Discharge, mgd Design	Receiving stream river kilometer
Monroe	L	1968	.04	.05	Long Tom - 10.5
Mt. Angel	TF	1955	.15	.36	Pudding - 55.8
Newberg	AS	1971	.60	2.00	Willamette - 80.9
Oak Hills	ASPL	1965	.18	.20	Willow Cr. - 4.3
Oaklodge	AS	1969	1.70	4.00	Willamette - 32.3
Oakridge	AS	1969	.44	.42	Mid Fork Willamette - 64.0
Oregon City	AS	1964	2.48	3.00	Willamette - 40.5
Philomath	AS	1952	.17	.35	Mary's R. - 18.5
Pleasant Valley Sch.	ASP	1963	.01	.01	Mitchell Cr.
Primate Center	ASP	1964	.05	.06	Bronson Cr. - 1.6
Ramada Inn	ASPL	1965	.03	.02	Tualatin - 12.9
River Vil. Trailer Park	ASP	1968	.00	.01	Willamette - 64.4
Riverview Heights	ASP	1960	.02	.05	Willamette - 185.0
Salem Willow Lake	TF	1964	23.70	17.50	Willamette - 125.8
Sandy	AS	1972	.13	.50	Trickle Cr. - 2.1
Scio	L	1963	.04	.06	Thomas Cr. - 12.9
Sherwood	TF	1965	.33	.57	Cedar Cr. - 1.8
Silverton	TF	1970	.43	.70	Silver Cr. - 5.6
Sommerset West	ASPL	1964	.39	.32	Beaverton Cr. - 12.1
Southwood Park	TF	1962	.08	.10	Ball Cr. - 1.9
Springfield	TF	1962	5.70	6.90	Willamette - 296.5
Stayton	ASEF	1964	.34	1.35	N. Santiam - 24.1
Sunset	AS	1965	1.10	1.50	Cedar Mill Cr - 4.8
Sweet Home	ASEF	1966	.40	.50	S. Santiam - 54.1
Tigard	AS	1970	.92	1.50	Fanno Cr. - 6.0
Tualatin	ASEF	1970	.16	.28	Tualatin - 13.8
Tual.Valley Develop.Co.	ASP	1965	.28	.20	Tualatin - 17.7
Twin Oaks School	TF	1959	.00	.01	Spencer Cr. - 7.7
Tyron	AS	1965	3.85	5.00	Willamette - 32.7
Westfir	ASP	1966	.03	.03	Mid Fork Willamette - 59.5
West Hills S.D.	ASP	1961	.02	.03	Oak Cr. - 2.1
West Linn Bolton	TF	1963	.44	1.30	Willamette - 38.8
West Linn Willamette	TF	1963	.20	.38	Willamette - 45.1
West Mod. Homes	ASP		.05	.05	Mill Cr. - 8.1
West Salem	AS	1969	.05	.40	Willamette - 128.7
Willow Is. Mobile Home	ASP	1973	.03	.03	Willamette
Wilsonville	ASP	1972	.15	.50	Willamette - 62.8
Woodburn	TF	1964	.60	.96	Pudding - 13.7
Yamhill	ASP	1964	.05	.10	Yamhill Cr. - 1.4

*TFEF = Trickling Filter with Effluent Filtration; ASEF = Activated Sludge with Effluent Filtration; ASP = Activated Sludge Package Plant; AS = Activated Sludge; TF = Trickling Filter; L = Lagoon; P= Primary; ASPL = Activated Sludge Package Plant with Lagoon.

TABLE A-19. MAJOR OPERATING INDUSTRIAL WASTEWATER TREATMENT PLANTS (3, 9, 10)

Plant and location	Type of process	Receiving stream river kilometer	Allowable summer discharges, kg/day	
			BOD5/suspended solids	Other*
American Can, Halsey	Bleached Kraft pulping and tissue wastes	Willamette - 238.8	1,100/3,200	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
Oregon Metallurgical, Albany	Titanium processing wastes	Oak Creek to Willamette - 192.6	0/70	Chlorides - 4,500 Fluorides - 9,000
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

109

TABLE A-19 (continued).

Plant and location	Type of process	Receiving stream river kilometer	Allowable summer discharges, kg/day		
			BOD5	suspended solids	Other*
Rhodia, Portland	Process waste from insecticide production	Willamette - 11.3	0/120		COD - 680 Dissolved solids - 21,000
Tektronix, Beaverton	Electroplating wastes	Beaverton Cr - 10.8 to Rock Cr to Tualatin - 61.9	0/110		Ammonium ion - 4.5
Wah Chang, Albany	Process waste from exotic metals production	Truax Cr - 3.2 to Willamette - 185.8	0/320		COD - 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
Weyerhaeuser, Springfield	Unbleached Kraft pulping and linerboard wastes	McKenzie - 23.7	1,400/4,500		None

* Inorganic waste streams have many other components.

APPENDIX B

DISCUSSION

The following discussion traces the computer modeling from data file creation to final simulated output. Figure B-25 illustrates in a schematic manner the data handling. Example data files and FORTRAN listings or routines follow in this appendix.

Total Loading (TL) Files

For each strategy of Valley pollution control, a stream-ordered listing of all known dischargers was created as a total loading (TL) data file. The example file TL1973 listed described the Willamette River dischargers of August 1973. Indentation signifies to what stream each discharge flows and to what stream each tributary discharges. British, rather than SI units, are used, conforming with raw data. River mile distance and stream velocity estimation allow calculation of travel time to the Willamette main stem for each up-tributary discharge. Tributary velocity is estimated from channel slope, summer discharge, and proximity to streams where velocities have been gaged (85).

Pollutant loadings are quantified as immediate oxygen demand (IOD), collodial/dissolved carbonaceous 5-day oxygen demand (BOD), settleable solids oxygen demand (not used in this study since settled solids are considered to exert IOD), Kjeldahl nitrogen, flow discharge, and dissolved oxygen saturation. The TL file incorporates all loadings: point source, nonpoint source (as equivalent point inputs at main stem tributary mouths), benthic demands, and abstractions (diversion of flow, BOD, and N from the main stem).

WILT

The routine WILT routed all tributary BOD and N to the Willamette main stem. Reaeration was not estimated; DO of the final main stem input is included in the TL data. Historically DO sag in tributaries has not been a major porblem. It was assumed that particular tributary quality problems, say eutrophied pools, can be resolved locally rather than as a regional concern.

WILT provided an output of a main stem loading (ML) file, a listing of first-column TL inputs, with loads now encompassing residual up-tributary oxygen-demanding discharges.

WILBER

The main stem hydraulic program, WILBER, collected all inputs from the ML file, read the design flow and percent DO saturation at Salem from a discharge (Q) file, and obtained the hydraulic constants for the Salem-Portland reaches from HYCONST. Main stem flow above Salem was routed to Salem through 7 upstream reaches. DO was not modeled in the upstream Willamette where the generally steep slopes keep the waters well aerated.

For reaches above the Newberg Pool, WILBER calculated channel depth by Manning's equation. HYDCONST gave channel width, slope and roughness while Q defined discharge. In and below the Newberg Pool, depth of summer flow does not vary with discharge because of downstream flow control. Therefore WILBER is directly given channel width and depth from HYDCONST.

WILBER generated a loading file (L) that resembles the ML file with the top boundary condition now at Salem. WILBER also generated hydraulic file (H) containing the milepoint, cross-sectional area, width, and inflow for each of the 297 downstream reaches.

WILMA

The basic DO smulation routine WILMA routed flow reach by reach from Salem to Portland. Velz's rational accounting method of DO was employed. WILMA drew data from a H and L file and a user written temperature file, T. In T, temperature can be given for any of the reach nodes. Nodes with unspecified temperature assume the value of the immediately upstream node. WILMA did the following:

1) Establishes deoxygenation rate constants and Velz stream type;
2) Converts BOD_5 into CBOD ultimate;
3) Converts Kjeldahl N into NBOD;
4) Calculates average area, temperature, depth, and DO saturation for each reach;
5) Corrects rate constants for temperature;
6) Determines oxygen, CBOD, and NBOD inputs at the top of each reach;
7) Determines CBOD and NBOD satisfied in each reach;
8) Removes IOD exerted;
9) Calculates reaeration in each reach;
10) Routes outputs to the downstream reach; and
11) Generates documentation including

   -   File name references,
   -   Lower mainstem loading summary,
   -   Temperature and saturation summary,
   -   Reach by reach hydraulic conditions,
   -   Reach by reach temperature-corrected rate constants,
   -   Reach by reach DO balance tabulation,
   -   Travel times to each reach node, and
   -   DO at each reach node.
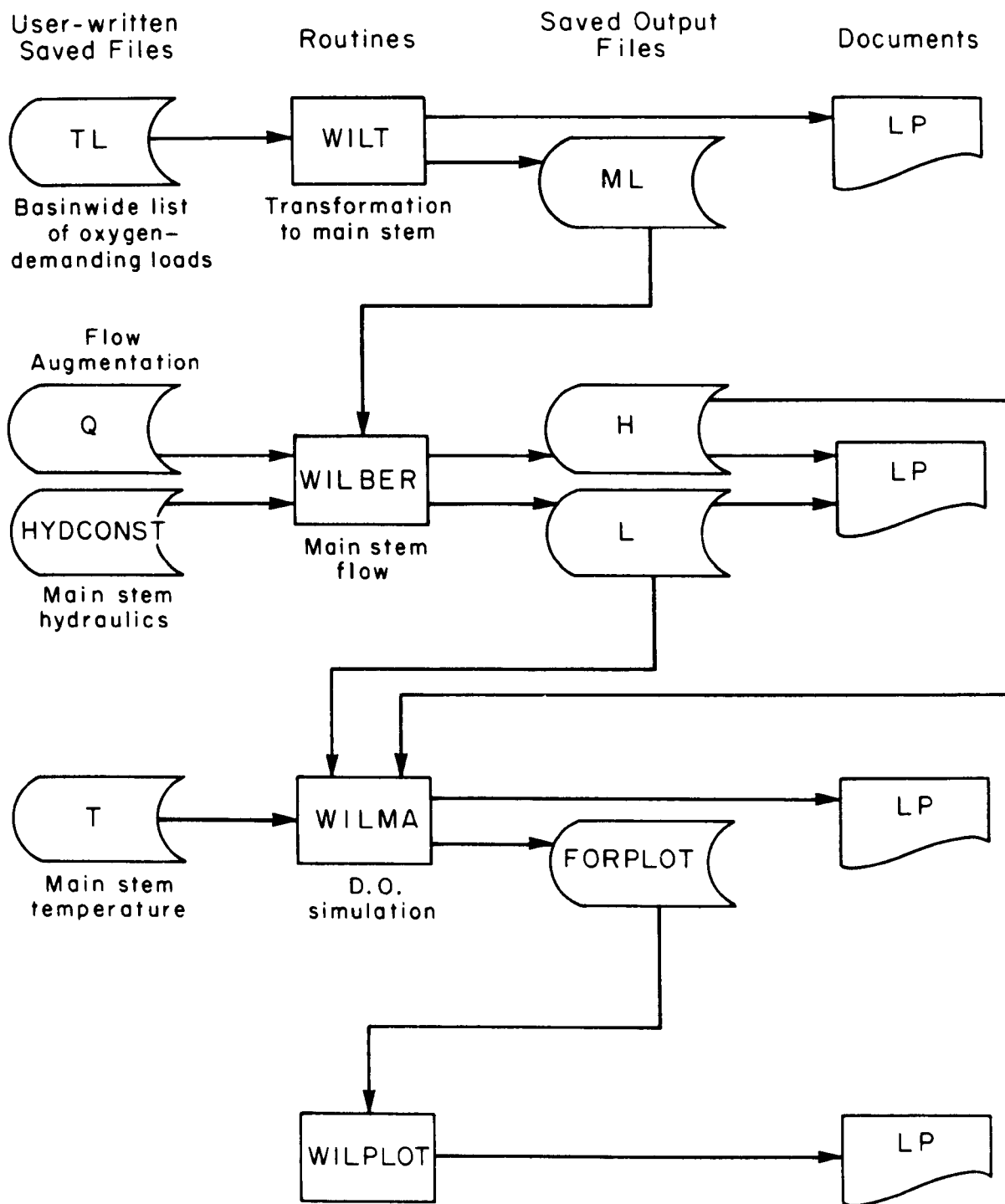
Figure B-25. Data handling schematic.

WILPLOT

The graphic routine WILPLOT plotted DO versus river kilometer from Salem to Portland. A FORPLOT file derived from WILMA provided inputs. Figure 16 in the main text illustrates the product.

Operation

All routines were designed to be run interactively. The operator must supply names, redefine logical units, copy, and save files. The system could be modified to be batch run, though run flexibility would be reduced. Interactively, the operator can recover and vary flow and loading files until the target output is achieved.

LISTINGS

Following are listings of sample user-written data files and FORTRAN routines. The lineprint output from WILMA is also illustrated. Program WIL-PLOT is not listed, as this routine is not readily transportable. A WILMA-written FORPLOT file, however, should be suitable input for graphic programs on any system.

TL File

TL1973

BENTHIC DEMAND	5.20		6000.				
BENTHIC DEMAND	6.20		6000.				
RHODIA	7.00			1500.		.20	.75
PENNWALT	7.20				150.	57.23	.75
BENTHIC DEMAND	8.23		6000.				
BENTHIC DEMAND	9.20		6000.				
BENTHIC DEMAND	12.84		6000.				
MILWAUKIE	18.39			200.	284.	2.63	.5
JOHNSON CREEK	18.40	2.				1.	.8
NPS				12.	18.		
MITCHELL CREEK	11.00	3.					
HAPPY VALLEY HOMES	1.30			1.5	1.	.01	.5
PLEASANT VALLEY SCH	1.30			1.	1.	.01	.5
OAKLODGE	19.90			525.	284.	2.63	.5
TYRON	20.23			349.	644.	5.96	.5
MARYLHURST	21.87			15.	83.	.96	.5
WEST LINN BOLTCN	24.14			131.	59.	.68	.5
CLACKAMAS RIVER	24.82	1.				853.	.96
NPS				2770.	108.		
DEEP CREEK	12.1	1.1					
TICKLE CREEK	2.9	1.2					
SANDY	1.3			22.	22.	.20	.5
ESTACADA	23.6			10.	16.	.19	.5
OREGON CITY	25.21			320.	415.	3.84	.5
PUBLISHERS PAPER	27.60			8000.		20.88	.5
WEST LINN WILLAMETTE	27.80			35.	27.	.31	.5
CROWN ZELLERBACH	28.00			4000.		22.89	.5
TUALATIN RIVER	28.45	.2				36.	.9
NPS				1643.	0.		
RAMADA INN	8.0			7.		.04	.5
TUALATIN	8.6			20.	16.	.25	.5
FANNO CREEK	9.4	.3					
BALL CREEK	2.0	.3					
SOUTHWOOD PARK	1.2			13.	10.	.12	.5
TIGARD	3.7			80.	154.	1.42	.5
METZGER	4.9			250.	241.	2.32	.5
FANNO	8.3			500.	526.	4.87	.5
TUAL VALLEY DEVELOP CO	11.0			50.	46.	.43	.5
CHICKEN CREEK	15.6	.3					
CEDAR CREEK	1.5	.4					
SHEPWOOD	1.1			80.	44.	.51	.5
ROCK CREEK	38.1	.3		160.	152.	1.41	.5
HILLSBORO	0.1						
BEAVERTON CREEK	4.3	.4		2.	2.	.02	.5
HILLSBORO JR HI	0.0						
BRONSON CREEK	1.0	.4					
PRIMATE CENTER	1.0			8.	9.	.08	.5
ALOHA	3.3			100.	121.	1.86	.5
WILLOW CREEK	6.5	.4					
OAK HILLS	2.7			32.		.28	.5
CEDAR MILL CREEK	7.0	.4					
SUNSET	3.0			190.	184.	1.70	.5
TEKTRONIX	7.0			60.	540.	.93	.5
BEAVERTON	8.0			300.	191.	2.94	.5
CEDAR HILLS	9.0			125.	123.	1.42	.5
SOMMERSET WEST	7.5			50.		.60	.5
HILLSBORO WEST	39.0			335.	145.	1.34	.5
DAIRY CREEK	44.8	.2					
WEST FORK DAIRY	10.0	.3					
BANKS	10.0			8.	8.	.07	.5
CORNELIUS	52.3			20.	28.	.32	.5
HILL CREEK	62.0	.4					
LAURELWOOD ACADEMY	6.0			7.	5.	.06	.5
GASTON	64.5			12.	6.	.06	.5
WILLOW IS MOBILE HOME	31.6			5.	6.	.05	.5
CANBY	33.0			71.	57.	.53	.5
MOLALLA RIVER	35.75	.4				77.	1.
NPS				180.	154.		
PUDDING RIVER	0.8	.2					
MILL CREEK	7.2	.3					
WEST MOD HOMES	5.0			8.5	9.	.08	.5
HUBBARD	5.3			18.	13.	.15	.5
WOODBURN	8.5			200.	80.	.93	.5
ROCK CREEK	15.5	.3					
BEAR CREEK	0.5	.4					
MOLALLA	10.0			60.	27.	.31	.5
BIRDSEYE	27.			250.		1.50	.5
MT ANGEL	34.7			50.	20.	.23	.5
SILVER CREEK	42.2	.3					
SILVERTON	3.5			80.	58.	.67	.5

WILSONVILLE	39.0		20.	57.	.23	.5
OAMMASCH HOSPITAL	39.8		20.	15.	.17	.5
ABSTRACTION	40.0		-255.	-74.	-70.	.85
RIVER VIL TRAILER PARK	40.2		1.	1.	.01	.5
CENTURY MEADOWS	42.		10.	6.	.06	.5
PUBLISHERS PAPER	49.8		6000.		14.23	.5
ABSTRACTION	50.0		-259.	-68.	-70.	.85
NEWBERG	50.5		115.	101.	.93	.5
DUNDEE	51.8		15.		.09	.5
YAMHILL	55.0	.3			37.	.9
NPS			285.	0.		
DAYTON	5.3		26.		.15	.5
LAFAYETTE	8.0		22.		.13	.5
NORTH FORK YAMHILL	11.2	.4				
CARLTON	6.0		25.	16.	.19	.5
YAMHILL CREEK	13.2	.4				
YAMHILL	0.9		11.	9.	.08	.5
SOUTH FORK YAMHILL	11.2	.4				
MCMINNVILLE	4.0		203.	322.	2.89	.5
EOLA VILLAGE	15.0		13.	10.	.12	.5
ABSTRACTION	60.0		-329.	-89.	-70.	.85
ABSTRACTION	70.0		-398.	-176.	-70.	.85
SALEM WILLOW LAKE	77.9		10000.	3000.	33.66	.1
GLEN CREEK	79.0	.5			0.	0.
WINSLOW CREEK	2.0	.5				
CHATNICKA HEIGHTS	4.5		2.	2.	.02	.5
WEST SALEM	80.		10.	8.	.07	.5
ABSTRACTION	81.0		-284.	-204.	-70.	.90
MILL CREEK	84.0	.5			46.	.9
BOISE CASCADE	85.0					
RICKREALL CREEK	88.1	.4	10000.	20000.	19.49	.5
NPS					4.	.9
DALLAS	10.5		16.	0.		
ASH CREEK	95.3	.5	47.	108.	1.08	.5
NPS					1.2	.8
INDEPENDENCE	1.3		0.	2.		
MONMOUTH	2.6		70.		1.23	.5
ABSTRACTION	100.		131.		.77	.5
LUCKIAMUTE RIVER	107.5	.5	-42.	-38.	-13.	.90
NPS					15.	.9
SANTIAM RIVER	109.0	1.6	202.	14.		
NPS					1702.	.9
COOKS CREEK	3.0	.9	7272.	779.		
MILLERSBURG SCHOOL	6.2					
JEFFERSON	7.0		2.		.02	.5
NORTH SANTIAM	11.7	2.6	26.		.15	.5
STAYTON	15.0					
SOUTH SANTIAM	11.7	1.3	60.	34.	.53	.5
THOMAS CREEK	2.0	1.2				
SCIO	8.0					
CROWN ZELLERBACH	16.5		11.0		.06	.5
LEBANON	17.4		3000.		7.13	.5
SWEET HOME	33.6		177.	91.	1.05	.5
RIVERVIEW HEIGHTS	115.0		100.	40.	.62	.5
WESTERN KRAFT	116.5		3.	2.	.02	.5
WAH CHANG	117.0		2500.		10.21	.5
UNIDENTIFIED	117.0		1000.	2000.	3.09	.5
ALBANY	119.0			13000.	0.	0.
OREGON METALLURGICAL	119.0		1112.	892.	8.25	.5
CALAPOOIA RIVER	119.5	.3			1.85	.5
NPS					24.	.9
CENTRAL LINN HI SCHOOL	22.1		310.	40.		
ABSTRACTION	120.		2.	2.	.02	.5
CORVALLIS	131.0		-39.	-3.	-13.	.90
MARYS RIVER	132.1	.3	2780.	883.	10.21	.5
NPS					11.	.9
OAK CREEK	1.1	.6	120.	0.		
WEST HILLS S D	1.3					
CORVALLIS MOBILE HOME	1.6		2.	2.	.02	.5
PHILOMATH	11.5		5.	3.	.03	.5
EVANS PRODUCTS	132.2		29.	28.	.26	.5
MUDDY CREEK	132.6	.2	2000.		2.66	.5
NPS					0.	0.
HALSEY	23.0		0.	0.		
COUNTRY SQUIRE	48.0		13.		.08	.5
CORVALLIS AIRPORT	138.0		3.		.03	.5
ABSTRACTION	140.		2.		.02	.5
LONG TOM RIVER	145.9	.4	-32.	-3.	-13.	.90
NPS					37.	.9
MONROE	6.5		490.	59.		
COYOTE CREEK	30.2	.4	11.		.07	.5
TWIN OAKS SCHOOL	4.8					
AMERICAN CAN	149.4		1.	1.	.01	.5
ABSTRACTION	160.		2500.		26.25	.5
			-41.	-3.	-13.	.9

HARRISBURG	161.0		32.	11.	.13	.5
ABSTRACTION	170.		-121.	-6.	-.45.	.90
MCKENZIE	171.8	2.6			2334.	1.
NPS			10387.	455.		
WEYERHAUSER	14.7		3000.		25.37	.5
EUGENE	178.0		5300.	1846.	21.35	.5
ABSTRACTION	180.		-110.	-6.	-.45.	.90
SPRINGFIELD	184.3		1612.	763.	8.82	.5
MIDDLE FORK	187.0	3.2			2210.	.9
NPS			12448.	401.		
LOWELL PARK	16.9		2.	1.	.01	.5
LOWELL	18.5		14.	75.	.87	.5
WESTFIR	37.0		8.	5.	.05	.5
OAKRIDGE	39.8		80.	74.	.68	.5
COAST FORK	187.0	.7			241.	.9
NPS			1034.	49.		
FIR COVE SANITATION	1.0		2.	1.	.01	.5
CAMAS SLOUGH	10.0	1.				
CRESWELL	5.0		30.		.19	.5
COTTAGE GROVE	22.		400.	123.	1.42	.5

T File

T20

86.50	20.00
53.40	20.20
53.20	20.40
53.00	20.60
52.90	20.80
52.60	21.00
45.85	21.20
45.60	21.40
45.40	21.60
45.20	21.80
45.00	22.00
37.80	22.20
37.60	22.40
37.40	22.60
37.20	22.80
37.00	23.00
26.37	23.10
26.20	23.20
26.00	23.30
25.74	23.40
25.56	23.50

Q File

6560.	.85

HYDCONST File

86.50	455	.00281	.02661
85.80	285	.00281	.03557
85.20	370	.00281	.03033
85.00	400	.00281	.02779
84.00	545	.00287	.02303
83.90	415	.00287	.01248
83.00	516	.00287	.01082
82.00	531	.00287	.01062
81.00	460	.00287	.01167
80.00	375	.00287	.01332
79.00	245	.00282	.01725
77.90	290	.00282	.01545
77.80	400	.00282	.02155
77.00	295	.00282	.02607
76.00	380	.00282	.02227
75.00	400	.00492	.02847
74.00	360	.00492	.03043
73.00	360	.00492	.03043
72.00	445	.00492	.02659
71.80	385	.00492	.02822
71.00	390	.00514	.02861
70.00	270	.00514	.03594
69.00	260	.00514	.03676
68.00	300	.00514	.03371
67.00	370	.00291	.02226
66.90	325	.00291	.02414
65.00	375	.00291	.02207
64.80	335	.00291	.03499
64.00	295	.00291	.03779
63.00	380	.00287	.03214
62.00	360	.00287	.03324
61.00	350	.00287	.03383
60.20	260	.00287	.04042
60.00	285	.00287	.01220
59.00	365	.00260	.00991
58.00	210	.00260	.01401
57.00	210	.00260	.01401
56.00	210	.00260	.01401
55.20	210	5.95	
55.00	367	9.06	
54.80	337	5.65	
54.60	510	4.56	
54.45	650	7.15	
54.20	470	11.97	
54.00	570	19.82	
53.80	618	7.80	
53.60	774	5.91	
53.40	640	5.45	
53.20	610	5.41	
53.00	467	12.85	
52.80	505	10.30	
52.60	600	23.46	
52.40	438	19.77	
52.20	720	8.97	
52.05	790	7.43	
51.80	710	11.80	
51.60	710	10.56	
51.40	770	11.05	
51.00	810	12.58	
50.80	950	15.86	
50.65	680	12.44	
50.50	690	11.43	
50.40	700	10.45	
50.20	650	21.24	
50.00	470	21.17	
49.80	520	22.40	
49.60	520	24.99	
49.40	520	20.83	
49.20	490	21.56	
49.00	500	22.94	
48.80	580	25.05	
48.60	440	24.74	
48.40	520	19.36	
48.20	570	17.05	
48.00	580	15.72	
47.75	638	15.40	
47.60	620	16.27	
47.40	680	15.90	
47.20	590	23.12	
47.00	550	22.67	
46.80	489	23.94	
46.55	570	24.09	
46.40	600	25.65	
46.20	550	21.36	
46.00	650	29.50	

45.85	600	32.39
45.60	657	23.67
45.40	465	26.42
45.20	725	23.21
45.00	780	17.87
44.75	520	25.42
44.55	570	27.75
44.40	580	27.92
44.20	657	26.79
44.05	580	30.00
43.90	570	30.83
43.60	580	30.33
43.40	650	24.86
43.20	580	30.09
43.00	566	23.42
42.80	590	35.39
42.60	680	23.26
42.40	586	24.26
42.20	550	29.90
42.00	635	20.52
41.80	616	27.65
41.60	530	30.05
41.40	565	23.29
41.20	690	25.51
41.00	680	22.73
40.80	650	20.36
40.60	620	23.11
40.40	600	29.12
40.20	620	23.45
40.00	640	21.27
39.80	565	29.34
39.60	600	25.21
39.40	617	22.45
39.25	636	20.58
39.00	605	22.29
38.75	550	21.45
38.60	600	25.03
38.40	650	28.73
38.20	550	31.32
38.00	570	30.03
37.80	550	32.62
37.60	650	27.07
37.40	700	25.01
37.20	690	23.01
37.00	650	22.73
36.90	650	21.16
36.60	612	26.85
36.40	650	25.20
36.20	730	22.00
35.75	600	33.94
35.60	570	19.42
35.45	700	23.40
35.20	620	22.37
35.00	620	31.78
34.80	630	31.56
34.60	750	22.13
34.40	780	17.39
34.26	580	37.95
34.20	700	24.74
34.00	860	37.66
33.90	550	29.98
33.60	600	23.71
33.30	780	9.76
33.05	1010	17.65
33.00	945	17.23
32.80	880	16.76
32.60	750	16.72
32.45	925	33.40
32.40	500	52.14
32.25	730	23.75
32.05	870	7.06
31.80	920	12.13
31.60	910	23.64
31.42	620	32.24
31.20	780	42.58
31.00	790	24.56
30.80	680	34.76
30.56	1100	9.79
30.20	420	20.97
30.00	310	56.47
29.80	570	21.04
29.60	1300	14.11
29.40	1090	23.73
29.20	1170	22.20

29.00	1300	16.75	13.22	1480	28.78
28.90	1200	14.64	13.00	1180	35.09
28.55	1190	18.82	12.94	1005	37.41
28.45	790	41.89	12.57	825	43.39
28.35	740	42.13	12.46	820	45.04
28.15	780	37.82	12.23	1060	43.74
28.02	910	33.52	12.00	820	55.49
28.00	960	32.96	11.77	745	49.32
27.96	960	30.20	11.60	1000	49.56
27.80	990	30.99	11.40	1265	43.00
27.60	1010	30.01	11.20	1185	41.27
27.40	910	33.55	11.00	1110	47.09
27.20	730	36.83	10.73	1145	49.94
27.00	1090	29.14	10.60	1160	45.82
26.99	200	10.00	10.40	1120	45.68
26.53	200	10.00	10.20	1210	43.55
26.52	400	29.98	10.00	1710	43.95
26.37	265	35.32	9.80	2430	33.33
26.20	395	54.63	9.60	1640	36.32
26.00	440	25.80	9.40	1630	35.46
25.74	370	15.54	9.20	1670	37.62
25.56	585	21.37	9.00	1710	46.82
25.37	360	11.67	8.80	2025	45.06
25.21	420	11.60	8.60	2360	40.62
25.00	405	10.86	8.40	2250	41.21
24.82	380	15.13	8.23	1760	48.43
24.58	660	10.91	7.90	2385	52.06
24.34	795	24.51	7.80	2935	47.02
24.14	725	15.98	7.60	2555	41.21
24.00	640	25.58	7.40	2060	44.34
23.84	660	33.23	7.20	2000	42.07
23.69	660	18.97	7.00	1740	41.58
23.53	610	20.06	6.96	1355	41.82
23.28	530	23.85	6.60	1414	43.99
23.00	924	23.25	6.40	1366	41.24
22.78	475	15.47	6.20	1340	41.72
22.61	290	36.28	6.00	1500	42.63
22.45	450	39.09	5.80	1210	43.67
22.27	460	38.20	5.60	1320	41.29
21.97	425	60.64	5.40	1290	43.96
21.68	685	20.29	5.20	1340	45.94
21.46	365	37.81	5.00	1500	45.51
21.23	425	95.80			
20.86	485	43.61			
20.68	660	40.64			
20.52	510	52.25			
20.23	565	47.36			
19.90	665	42.09			
19.77	900	35.81			
19.57	670	60.30			
19.40	870	40.53			
19.14	640	70.86			
19.00	515	39.28			
18.86	905	44.09			
18.58	1110	49.51			
18.50	948	47.52			
18.40	948	47.52			
18.39	948	47.52			
18.36	785	46.18			
18.17	845	34.65			
18.10	810	35.06			
17.92	690	46.96			
17.73	750	46.31			
17.54	690	45.04			
17.35	760	52.87			
17.16	955	51.48			
17.10	1090	58.40			
16.96	1231	34.44			
16.68	1000	25.25			
16.43	960	54.93			
16.16	720	44.47			
16.00	1260	24.65			
15.92	1505	24.78			
15.57	1770	142.90			
15.39	1190	28.87			
15.22	1216	27.42			
15.10	1075	29.10			
14.78	800	25.40			
14.52	735	33.65			
14.35	655	45.80			
14.19	720	36.67			
14.00	1560	26.89			
13.92	1320	36.36			
13.57	1290	30.84			
13.41	1270	30.31			

<u>WILT</u>

```
      PROGRAM WILT                                                     A  1
      DIMENSION MORD(5), NORD(200), TITLE(200,3), X(200,8), TOT(200),  A  2
     $ AK1(200), AKN(200)                                              A  3
      READ (1,15) TNULL                                                A  4
      N = 0                                                            A  5
      NMS = 0                                                          A  6
      DO 2 I=1,200                                                     A  7
         IF (ECF(1)) GO TO 3                                           A  8
         N = N+1                                                       A  9
         READ (1,16) MORD                                             A 10
         DO 1 J=1,5                                                    A 11
            IF (MORD(J).EQ.#     #) GO TO 1                            A 12
            NORD(I) = J                                                A 13
            GO TO 2                                                    A 14
    1    CONTINUE                                                      A 15
    2 CONTINUE                                                         A 16
    3 REWIND 1                                                         A 17
      READ (1,15) TLTIT                                                A 18
      READ (1,17) ((TITLE(I,J),J=1,3),(X(I,J),J=1,8),I=1,N)           A 19
      C = .05111                                                       A 20
      DO 10 I=1,N                                                      A 21
         GO TO (4,5,6,7,8), NORD(I)                                    A 22
    4    VEL1 = X(I,2)                                                 A 23
         TOT(I) = 0.                                                   A 24
         GO TO 9                                                       A 25
    5    VEL2 = X(I,2)                                                 A 26
         TOT2 = X(I,1)/VEL1*C                                          A 27
         TOT(I) = TOT2                                                 A 28
         GO TO 9                                                       A 29
    6    VEL3 = X(I,2)                                                 A 30
         TOT3 = TOT2+X(I,1)/VEL2*C                                     A 31
         TOT(I) = TOT3                                                 A 32
         GO TO 9                                                       A 33
    7    VEL4 = X(I,2)                                                 A 34
         TOT4 = TOT3+X(I,1)/VEL3*C                                     A 35
         TOT(I) = TOT4                                                 A 36
         GO TO 9                                                       A 37
    8    VEL5 = X(I,2)                                                 A 38
         TOT(I) = TOT4+X(I,1)/VEL4*C                                   A 39
    9    AK1(I) = .06                                                  A 40
         AKN(I) = .1                                                   A 41
   10 CONTINUE                                                         A 42
      K = N                                                            A 43
      TBOD2 = 0.                                                       A 44
      TBODN = 0.                                                       A 45
   11 CONTINUE                                                         A 46
      IF (NORD(K).EQ.1) GO TO 12                                       A 47
      TBOD2 = TBOD2+X(K,4)*10.**(-AK1(K)*TOT(K))                       A 48
      TBODN = TBODN+X(K,6)*10.**(-AKN(K)*TOT(K))                       A 49
      GO TO 13                                                         A 50
   12 X(K,4) = X(K,4)+TBOD2                                            A 51
      X(K,6) = X(K,6)+TBODN                                            A 52
      NMS = NMS+1                                                      A 53
      TBOD2 = 0.                                                       A 54
      TBODN = 0.                                                       A 55
   13 K = K-1                                                          A 56
      IF (K.GE.1) GO TO 11                                             A 57
      WRITE (2,18) TLTIT                                               A 58
      WRITE (2,17) ((TITLE(I,J),J=1,3),(X(I,J),J=1,8),I=1,N)          A 59
      WRITE (3,19) TLTIT,NMS                                           A 60
      DO 14 I=1,N                                                      A 61
         IF (NORD(I).NE.1) GO TO 14                                    A 62
         WRITE (3,17) (TITLE(I,J),J=1,3),(X(I,J),J=1,8)               A 63
   14 CONTINUE                                                         A 64
      CALL EXIT                                                        A 65
                                                                       A 66
    C                                                                  A 67
   15 FORMAT (A8)                                                      A 68
   16 FORMAT (5A1)                                                     A 69
   17 FORMAT (3A8,2F7.2,4F7.0,2F7.2)                                   A 70
   18 FORMAT (/DATA FROM FILE #,A8//26X,#RIVER    VEL ***LBS #,#PER DAY B A 71
     $OD***    PPD    FLOW    PCT#/# FACILITY AND LOCATION#,#    MILE  A 72
     $FPS  IMMED COL/DIS SOLID    NITR    CFS    SAT#)                 A 73
   19 FORMAT (#FROM FILE #,A8/I3,# INFLOWS#)                           A 74-
      END
```

TABLE B-22. LISTING OF WILBER PROGRAM

WILBER

```
      PRCGRAM WILBER                                                    A    1
      DIMENSION TITLE(200,3), X(200,8), RT(6), Q(7), V(7), TOT(2C0), YMP A    2
     *(297), YK(297), YS(297), YN(297), YQ(297), YA(297), YOIN(297), OEP A    3
     *(297)                                                              A    4
      IWILMA = 0                                                         A    5
      T8001 = 0.                                                         A    6
      T8002 = 0.                                                         A    7
      T8003 = 0.                                                         A    8
      T800N = 0.                                                         A    9
      READ (2,23) TLTIT,NMS                                              A   10
      READ (2,24) ((TITLE(I,J),J=1,3),(X(I,J),J=1,8),I=1,NMS)           A   11
      READ (3,25) Q841,TPCT                                             A   12
      Q(1) = .9936*Q841                                                 A   13
      Q(2) = .7287*Q841                                                 A   14
      Q(3) = .7250*Q841                                                 A   15
      Q(4) = .7234*Q841                                                 A   16
      Q(5) = .7208*Q841                                                 A   17
      C(6) = .3700*Q841                                                 A   18
      Q(7) = .3700*Q841                                                 A   19
      V(1) = .08857*Q(1)**0.391                                         A   20
      V(2) = .02590*Q(2)**0.527                                         A   21
      V(3) = .03252*Q(3)**0.513                                         A   22
      V(4) = .00602*Q(4)**0.698                                         A   23
      V(5) = .02290*Q(5)**0.585                                         A   24
      V(6) = .00615*Q(6)**0.712                                         A   25
      V(7) = .01860*Q(7)**0.576                                         A   26
      C = .06111                                                        A   27
      RT(1) = 22.5/V(1)*C                                               A   28
      RT(2) = 10.5/V(2)*C+RT(1)                                         A   29
      RT(3) = 12.6/V(3)*C+RT(2)                                         A   30
      RT(4) = 13.8/V(4)*C+RT(3)                                         A   31
      RT(5) = 25.9/V(5)*C+RT(4)                                         A   32
      RT(6) = 8./V(6)*C+RT(5)                                           A   33
      AK1 = .04                                                         A   34
      AKN = .2                                                          A   35
      DO 1 I=1,NMS                                                      A   36
      IF (X(I,1).GE.86.5) GO TO 2                                       A   37
    1 IWILMA = IWILMA+1                                                 A   38
    2 ITOP = IWILMA+1                                                   A   39
      DO 11 I=ITOP,NMS                                                  A   40
      IF (X(I,1).LE.109.0) GO TO 3                                      A   41
      IF (X(I,1).LE.119.5) GO TO 4                                      A   42
      IF (X(I,1).LE.132.1) GO TO 5                                      A   43
      IF (X(I,1).LE.145.9) GO TO 6                                      A   44
      IF (X(I,1).LE.171.8) GO TO 7                                      A   45
      IF (X(I,1).LE.179.8) GO TO 8                                      A   46
      GO TO 9                                                           A   47
    3 TOT(I) = (X(I,1)-86.5)/V(1)*C                                     A   48
      GO TO 10                                                          A   49
    4 TOT(I) = (X(I,1)-109.0)/V(2)*C+RT(1)                             A   50
      GO TO 10                                                          A   51
    5 TOT(I) = (X(I,1)-119.5)/V(3)*C+RT(2)                             A   52
      GO TO 10                                                          A   53
    6 TOT(I) = (X(I,1)-132.1)/V(4)*C+RT(3)                             A   54
      GO TO 10                                                          A   55
    7 TOT(I) = (X(I,1)-145.9)/V(5)*C+RT(4)                             A   56
      GO TO 10                                                          A   57
    8 TOT(I) = (X(I,1)-171.8)/V(6)*C+RT(5)                             A   58
      GO TO 10                                                          A   59
    9 TOT(I) = (X(I,1)-179.8)/V(7)*C+RT(6)                             A   60
   10 T8002 = T8002+X(I,4)*10.**(-AK1*TOT(I))                          A   61
   11 T800N = T800N+X(I,6)*10.**(-AKN*TOT(I))                          A   62
      IF (X(ITOP,1).NE.86.5) GO TO 12                                  A   63
      T8001 = X(ITOP,3)                                                A   64
      T8003 = X(ITOP,5)                                                A   65
   12 IUP = IWILMA                                                     A   66
      QUP = 0.                                                         A   67
   13 CONTINUE                                                         A   68
      IF (X(IUP,1).LE.84.1) GO TO 14                                   A   69
      QUP = QUP+X(IUP,7)                                               A   70
      IUP = IUP-1                                                      A   71
      GO TO 13                                                         A   72
   14 QUP = Q841-QUP                                                   A   73
      WRITE (5,26) T8001,T8002,T8003,T800N,TPCT                       A   74
      I = IWILMA                                                       A   75
   15 WRITE (5,27) X(I,1),(X(I,J),J=3,6),X(I,8),(TITLE(I,J),J=1,3)     A   76
      IF (I.EQ.1) GO TO 16                                             A   77
      I = I-1                                                          A   78
      GO TO 15                                                         A   79
```

```
16 READ (1,29) (YMP(I),YW(I),YS(I),YN(I),I=1,38)          A  80
   READ (1,29) (YMP(I),YW(I),DEP(I),I=39,297)             A  81
   YQ(1) = CUP                                            A  82
   YQIN(1) = QUP                                          A  83
   YQTOT = CUP                                            A  84
   K = IWILMA                                             A  85
   DO 18 I=2,297                                          A  86
      IF (K.LE.0) GO TO 17                                A  87
      IF (X(K,1).LT.YMP(I)) GO TO 17                      A  88
      YQTOT = YQTOT+X(K,7)                                A  89
      K = K-1                                             A  90
17    YQ(I) = YQTOT                                       A  91
18 YQIN(I) = YQ(I)-YQ(I-1)                                A  92
   D = 5.                                                 A  93
   DO 20 I=1,38                                           A  94
      A = YN(I)*YQ(I)/(1.49*YS(I)**.5*YW(I)**1.66666)     A  95
      A = A**1.5                                          A  96
      IT = I                                              A  97
      KOUNT = 0                                           A  98
      STEP = .005                                         A  99
      SIGN = +1.                                          A 100
      PROP = 2.                                           A 101
      W = YW(I)                                           A 102
      RHS = D**2.5/A-2.*D                                 A 103
      IF(RHS.GT.W)SIGN = -1.                              A 104
19    RHSLAST = RHS                                       A 105
      KOUNT = KOUNT+1                                     A 106
      IF (KOUNT.GT.40) GO TO 22                           A 107
      STEP = SIGN*PROP*STEP                               A 108
      IF(STEP.LT.-D)STEP = -D                             A 109
      D = D+STEP                                          A 110
      RHS = D**2.5/A-2.*D                                 A 111
      IF (ABS(RHS-W).LT..01) GO TO 20                     A 112
      SIGN = +1.                                          A 113
      IF ((RHS-W)*(RHSLAST-W).GT.0.) GO TO 19             A 114
      SIGN = -1.                                          A 115
      PROP = .5                                           A 116
      GO TO 19                                            A 117
20 YA(I) = D*YW(I)                                        A 118
   DO 21 I=39,297                                         A 119
21 YA(I) = DEP(I)*YW(I)                                   A 120
   WRITE (4,30) (I,YMP(I),YA(I),YW(I),YQIN(I),I=1,297)    A 121
   CALL EXIT                                              A 122
22 WRITE (61,31) IT                                       A 123
   CALL EXIT                                              A 124
 C                                                        A 125
23 FORMAT (10X,A8/I3)                                     A 126
24 FORMAT (3A8,2F7.2,4F7.0,2F7.2)                         A 127
25 FORMAT (2F10.0)                                        A 128
26 FORMAT (* 86.50*,4F10.0,F6.2,*  TOP OF MODEL*)         A 129
27 FORMAT (F6.2,4F10.0,F6.2,2X,3A8)                       A 130
28 FORMAT (F6.2,F5.0,F8.6,F8.5)                           A 131
29 FORMAT (F6.2,F5.0,F8.2)                                A 132
30 FORMAT (I3,F6.2,F7.0,F5.0,F8.2)                        A 133
31 FORMAT (* ITERATION*,I4)                               A 134
   END                                                    A 135-
```

```
WILMA
      PROGRAM WILMA                                                        A   1
      DIMENSION X(297), A(297), W(297), T(297), D(297), V(297), AVT(297)   A   2
     $, AVA(297), AVD(297), Q(297), QIN(297), TIN(297), TTO(297), NTYPE    A   3
     $(297), AK1(297), AKZ(297), AKN(297), BOD(3,297), BCDN(297), PCTIN    A   4
     $(297), DCIN(297), DOUS(297), BODIN(297), RCUS(297), RNUS(297),       A   5
     $ BODSAT(297), PCTUS(297), S(297), AVS(297), PCTOP(297), REAER(297)   A   6
     $, IRT(297), IRL(297), PPM(297), XKM(297)                             A   7
C                                                                          A   8
C     SET COMMON REACH PARAMETERS                                         A   9
C                                                                          A  10
      DO 1 I=1,39                                                          A  11
         NTYPE(I) = 1                                                      A  12
         AKZ(I) = .05                                                      A  13
    1 AKN(I) = .4                                                          A  14
      DO 2 I=39,185                                                        A  15
         NTYPE(I) = 1                                                      A  16
         AKZ(I) = .02                                                      A  17
    2 AKN(I) = .0                                                          A  18
      DO 3 I=185,297                                                       A  19
         NTYPE(I) = 2                                                      A  20
         AKZ(I) = .02                                                      A  21
    3 AKN(I) = 0.                                                          A  22
C                                                                          A  23
C     READ HYDRAULIC DATA                                                 A  24
C                                                                          A  25
      READ (1,30) TITH                                                     A  26
      READ (1,31) (X(I),A(I),W(I),QIN(I),I=1,297)                          A  27
C                                                                          A  28
C     READ AND SET TEMPERATURES                                           A  29
C                                                                          A  30
      READ (2,30) TITT                                                     A  31
      KT = 0                                                               A  32
      NLAST = 0                                                            A  33
    4 NSTART = NLAST+1                                                     A  34
      READ (2,32) XTEST,TT                                                 A  35
      IF (EOF(2)) GO TO 7                                                  A  36
      DO 6 I=NSTART,297                                                    A  37
         IF (X(I)-XTEST) 28,5,6                                            A  38
    5    T(I) = TT                                                         A  39
         KT = KT+1                                                        A  40
         IPT(KT) = I                                                       A  41
         NLAST = I                                                         A  42
         GO TO 4                                                           A  43
    6 T(I) = T(I-1)                                                        A  44
    7 CONTINUE                                                             A  45
      IF (NLAST.EQ.297) GO TO 9                                            A  46
      DO 8 I=NSTART,297                                                    A  47
    8 T(I) = T(I-1)                                                        A  48
    9 CONTINUE                                                             A  49
C                                                                          A  50
C     READ LOADINGS                                                       A  51
C                                                                          A  52
      READ (3,30) TITL                                                     A  53
      KL = 0                                                               A  54
      NLAST = 0                                                            A  55
   10 NSTART = NLAST+1                                                     A  56
      READ (3,33) XTEST,B1,B2,B3,BN,PCTX                                   A  57
      IF (EOF(3)) GO TO 12                                                 A  58
      DO 12 I=NSTART,297                                                   A  59
         IF (X(I)-XTEST) 28,11,12                                         A  60
   11    PCTIN(I) = PCTX                                                   A  61
         BOD(1,I) = B1                                                     A  62
         BOD(2,I) = B2*2.004                                              A  63
         BOD(3,I) = B3                                                     A  64
         BODN(I) = BN*4.3                                                 A  65
         KL = KL+1                                                        A  66
         IRL(KL) = I                                                       A  67
         NLAST = I                                                         A  68
         GO TO 10                                                          A  69
   12 CONTINUE                                                             A  70
C                                                                          A  71
C     EVALUATE REACH                                                      A  72
C                                                                          A  73
      Q(1) = QIN(1)                                                        A  74
      D(1) = A(1)/W(1)                                                     A  75
      S(1) = 14.35278-.32276*T(1)+.0032*T(1)**2                           A  76
      XKM(1) = X(1)*1.60934                                               A  77
      DO 19 M=1,296                                                        A  78
         N = M+1                                                          A  79
         Q(N) = Q(M)+QIN(N)                                               A  80
         D(N) = A(N)/W(N)                                                 A  81
```

123

```
        S(N)  = 14.35278-.32276*T(N)+.0032*T(N)**2          A 82
        XKM(N) = X(N)*1.60934                                A 83
        AVA(M) = .5*(A(M)+A(N))                              A 84
        AVT(M) = .5*(T(M)+T(N))                              A 85
        AVD(M) = .5*(D(M)+D(N))                              A 86
        AVS(M) = 14.35278-.32276*AVT(M)+.0032*AVT(M)**2      A 87
        AK1(M) = AKZ(M)*1.047**(AVT(M)-20.)                  A 88
        TIN(M) = AVA(M)*(X(M)-X(N))/(Q(M)*16.3636)           A 89
        TTO(N) = TTO(M)+TIN(M)                               A 90
        V(M)  = (X(M)-X(N))/TIN(M)                           A 91
        GO TO (13,14), NTYPE(M)                              A 92
13      AMI  = 1.79753+3.09053*AVD(M)-.08841*AVD(M)**2+.00092*AVD(M)**3  A 93
        GO TO 15                                             A 94
14      AMI  = 1.42624+2.21515*AVD(M)-.06136*AVD(M)**2+.00063*AVD(M)**3  A 95
15      DOIN(M) = DOUS(M)+QIN(M)*PCTIN(M)*S(M)*5.3913        A 96
        PCTOP(M) = ((Q(M)-QIN(M))*PCTUS(M)+QIN(M)*PCTIN(M))/Q(M)  A 97
        IF(M.EQ.185)DOIN(M) = DOIN(M)+7.83*QIN(1)*(1.-PCTOP(M))  A 98
        BODIN(M) = RCUS(M)+RNUS(M)+BOD(1,M)+BOD(2,M)+BOD(3,M)+BODN(M)  A 99
        RCUS(N) = (RCUS(M)+BOD(2,M))*10.**(-AK1(M)*TIN(M))   A 100
        RNUS(N) = (RNUS(M)+BODN(M))*10.**(-AKN(M)*TIN(M))    A 101
        BODSAT(M) = BODIN(M)-RCUS(N)-RNUS(N)                 A 102
        Y  = AVS(M)*AVA(M)*(X(M)-X(N))*2.7016*1.1**(AVT(M)/2.-10.)/(AVD  A 103
     $  (M)*SQRT(AMI))                                       A 104
        SATOUT = Q(M)*S(N)*5.39136                           A 105
        K = 0                                                A 106
        PCTEST = PCTOP(M)                                    A 107
16      REAER(M) = (1.-.5*(PCTEST+PCTOP(M)))*Y               A 108
        Z = (REAER(M)+DOIN(M)-BODSAT(M))/SATOUT              A 109
        K = K+1                                              A 110
        IF (K.GT.20) GO TO 29                                A 111
        IF (ABS(Z-PCTEST).LE..0001) GO TO 17                A 112
        PCTEST = Z                                           A 113
        GO TO 16                                             A 114
17      PCTUS(N) = Z                                         A 115
        PPM(M) = S(M)*PCTOP(M)                               A 116
18 DOLS(N) = Z*SATOUT                                        A 117
   BODIN(297) = RCUS(297)+RNUS(297)+BOD(1,297)+BOD(2,297)+BOD(3,297)+  A 118
     $BODN(297)                                              A 119
   DOIN(297) = DOUS(297)+QIN(297)*PCTIN(297)*S(297)*5.3913   A 120
   PCTOP(297) = (Q(296)*PCTUS(297)+QIN(297)*PCTIN(297))/Q(297)  A 121
   PPM(297) = S(297)*PCTOP(297)                              A 122
C                                                            A 123
C       LOADING OUTPUT                                       A 124
C                                                            A 125
   WRITE (5,34) TITH,TITT,TITL                               A 126
   WRITE (5,35)                                              A 127
   DO 19 K=1,KL                                              A 128
   I = IRL(K)                                                A 129
19 WRITE (5,36) I,X(I),BOD(1,I),BOD(2,I),BOD(3,I),BODN(I),QIN(I),  A 130
     $PCTIN(I)                                               A 131
C                                                            A 132
C       TEMPERATURE OUTPUT                                   A 133
C                                                            A 134
   WRITE (5,34) TITH,TITT,TITL                               A 135
   WRITE (5,37)                                              A 136
   DO 20 K=1,KT                                              A 137
   I = IRT(K)                                                A 138
20 WRITE (5,38) I,X(I),T(I),S(I)                             A 139
C                                                            A 140
C       REACH OUTPUT                                         A 141
C                                                            A 142
   WRITE (5,34) TITH,TITT,TITL                               A 143
   DO 27 KPAGE=1,5                                           A 144
   IF (KPAGE.NE.1) WRITE (5,39)                              A 145
   GO TO (21,22,23,24,25), KPAGE                             A 146
21      MT = 1                                               A 147
        MB = 67                                              A 148
        GO TO 26                                             A 149
22      MT = 68                                              A 150
        MB = 141                                             A 151
        GO TO 26                                             A 152
23      MT = 142                                             A 153
        MB = 215                                             A 154
        GO TO 26                                             A 155
24      MT = 216                                             A 156
        MB = 289                                             A 157
        GO TO 26                                             A 158
25      MT = 290                                             A 159
        MB = 296                                             A 160
26      WRITE (5,40)                                         A 161
27 WRITE (5,41) (I,X(I),AVA(I),AVD(I),AVT(I),Q(I),V(I),AK1(I),AKN(I),  A 162
     $BODIN(I),BODSAT(I),RCUS(I+1),RNUS(I+1),DOIN(I),REAER(I),DOUS(I+1),  A 163
     $TTO(I),PCTOP(I),PPM(I),I=MT,MB)                        A 164
```

```
      I = 297                                                               A 165
      WRITE (5,42) I,X(I),O(I),BODIN(I),DOIN(I),TTO(I),PCTOP(I),PPM(I)      A 166
C                                                                           A 167
C     PLOT OUTPUT                                                           A 168
C                                                                           A 169
      WRITE (4,43) (I,X(I),XKM(I),PPM(I),I=1,297)                           A 170
      CALL EXIT                                                             A 171
C                                                                           A 172
C     ERROR TERMINATIONS                                                    A 173
C                                                                           A 174
   28 WRITE (5,44) XTEST                                                    A 175
      CALL EXIT                                                             A 176
   29 WRITE (5,45) N                                                        A 177
      CALL EXIT                                                             A 178
C                                                                           A 179
   30 FORMAT (A8)                                                          A 180
   31 FORMAT (3X,F6.2,F7.0,F5.0,F8.2)                                       A 181
   32 FORMAT (2F10.0)                                                       A 182
   33 FORMAT (F6.2,4F10.0,F6.2)                                             A 183
   34 FORMAT (#1WILLAMETTE DISSOLVED OXYGEN MODEL#//# HYDRAULIC DATA FRO    A 184
     $M FILE #,A8/# TEMPERATURE DATA FROM FILE #,A8/# LOADING DATA FROM     A 185
     $FILE #,A8//)                                                         A 186
   35 FORMAT (15X,#**********LBS OF BOD DISCHARGED DAILY**********  *ADD    A 187
     $ED FLOW*#//# REACH MILE   IMMEDIATE   COLLOIDAL  SETTLEABLE  NITR     A 188
     $OGENOUS#,5X,#CFS    PCT#/9X,#PT#,16X,#DISSOLVED      SOLIDS#,27X,     A 189
     $#SAT#/)                                                              A 190
   36 FORMAT (I5,F7.2,4F12.0,F9.0,F7.2)                                     A 191
   37 FORMAT (# REACH  MILE   TEMPERATURE   DO SAT#/9X,#PT#,8X,#C#,9X,      A 192
     $#PPM#/)                                                              A 193
   38 FORMAT (I5,F7.2,F10.2,F11.3)                                          A 194
   39 FORMAT (#1#)                                                          A 195
   40 FORMAT (F1X,#****************BALANCE LBS PER DAY***************       A 196
     $****TOP OF REACH***#//16X,#***AVERAGE REACH CONDITIONS***    CONSTAN  A 197
     $TS  *************BOD************  **DISSOLVED OXYGEN**#,11X,          A 198
     $#****DO****#//# REACH  MILE    XSEC  DEPTH  TEMP    Q     VEL    KC    A 199
     $   KN    INITIAL SATIS-   FINAL     INITIAL REAER  FINAL   TIM        A 200
     $E    PCT     PPM#/9X,#PT      SQFT   FT     C     CFS    MPD    BASE   A 201
     $ 10#,12X,# FIED   CARB   NITR#,26X,#DAYS   SAT#/)                     A 202
   41 FORMAT (I5,F7.2,F8.0,F6.2,F7.2,F7.0,F6.2,F6.3,F6.3,F9.0,F6.0,F8.0,    A 203
     $F7.0,F9.0,F6.0,F8.0,F7.3,F7.2,F7.3)                                   A 204
   42 FORMAT (I5,F7.2,21X,F7.0,18X,F9.0,21X,F9.0,14X,F7.3,F7.2,F7.3)        A 205
   43 FORMAT (I4,3F10.4)                                                    A 206
   44 FORMAT (# NO REACH STARTS AT #,F6.2)                                  A 207
   45 FORMAT (# K OVER 20 WHEN N =#,I4)                                     A 208
      END                                                                  A 209-
```

TABLE B-24. EXAMPLES OF COMPUTER OUTPUT

WILLAMETTE DISSOLVED OXYGEN MODEL

HYDRAULIC DATA FROM FILE H73
TEMPERATURE DATA FROM FILE T20
LOADING DATA FROM FILE L73

REACH	MILE PT	**LBS OF BOD DISCHARGED DAILY** IMMEDIATE	COLLOIDAL DISSOLVED	SETTLEABLE SOLIDS	NITROGENOUS	*ADDED FLOW* CFS	PCT SAT
1	86.50	0	98523	0	60574	6541	.95
4	85.00	0	20040	0	86000	19	.50
5	84.00	0	0	0	0	46	.90
9	81.00	0	-569	0	-877	-70	.90
10	80.00	0	20	0	34	0	.50
11	79.00	0	4	0	9	0	0
12	77.90	0	20040	0	12900	34	.10
22	70.00	0	-798	0	-757	-70	.85
34	60.00	0	-659	0	-383	-70	.85
40	55.00	0	982	0	774	37	.90
56	51.80	0	30	0	0	0	.50
62	50.50	0	230	0	434	1	.50
65	50.00	0	-519	0	-292	-70	.85
66	49.80	0	12024	0	0	14	.50
105	42.00	0	20	0	26	0	.50
114	40.20	0	2	0	4	0	.50
115	40.00	0	-511	0	-318	-70	.85
116	39.80	0	40	0	64	0	.50
120	39.00	0	40	0	245	0	.50
136	35.75	0	876	0	886	77	1.00
151	33.00	0	142	0	245	1	.50
159	31.60	0	10	0	26	0	.50
174	28.45	0	4876	0	2012	36	.90
178	28.00	0	8016	0	0	23	.50
180	27.80	0	70	0	116	0	.50
181	27.60	0	16032	0	0	21	.50
194	25.21	0	641	0	1785	4	.50
196	24.82	0	5605	0	589	853	.96
199	24.14	0	263	0	254	1	.50
210	21.37	0	30	0	357	1	.50
217	20.23	0	699	0	2769	6	.50
218	19.90	0	1052	0	1221	3	.50
227	18.40	0	28	0	86	1	.80
228	18.39	0	401	0	1221	3	.50
265	12.84	6000	0	0	0	0	0
276	9.20	6000	0	0	0	0	0
281	8.23	6000	0	0	0	0	0
286	7.20	0	0	0	0	0	0
287	7.00	0	3006	0	645	57	.75
291	6.20	6000	0	0	0	0	.75
296	5.20	6000	0	0	0	0	0

WILLAMETTE DISSOLVED OXYGEN MODEL

HYDRAULIC DATA FROM FILE H73
TEMPERATURE DATA FROM FILE T20
LOADING DATA FROM FILE L73

REACH	MILE PT	TEMPERATURE C	DO SAT PPM
1	86.50	20.00	9.178
48	53.40	20.20	9.139
49	53.28	20.48	9.100
50	53.00	20.60	9.062
51	52.80	20.90	9.024
52	52.60	21.00	8.986
86	45.85	21.20	8.948
87	45.60	21.40	8.911
88	45.40	21.60	8.874
89	45.20	21.80	8.837
90	45.00	22.00	8.801
126	37.80	22.20	8.765
127	37.60	22.40	8.729
128	37.40	22.50	8.693
129	37.20	22.90	8.657
130	37.00	23.00	8.622
188	26.37	23.10	8.605
189	26.20	23.20	8.587
190	26.00	23.30	8.570
191	25.74	23.40	8.552
192	25.56	23.50	8.535

TABLE B-24 (continued)

REACH	MILE PT	***AVERAGE REACH CONDITIONS*** XSEC SQFT	DEPTH FT	TEMP C	Q CFS	VEL MPD	CONSTANTS KC BASE 10	KN	*BALANCE LBS PER DAY* BOD INITIAL	SATIS-FIED	FINAL CARB	NITR	DISSOLVED OXYGEN INITIAL	REAER	FINAL	TOP OF REACH DO TIME DAYS	PCT SAT	PPM
1	86.50	2361	6.74	20.00	6541	45.33	.050	.400	159097	1030	98348	59719	275076	212	274257	0	.85	7.801
2	85.40	2362	7.33	20.00	6541	45.32	.050	.400	158066	874	98195	58995	274257	164	273548	.015	.85	7.775
3	85.20	2336	6.09	20.00	6541	45.82	.050	.400	157193	286	98149	59758	273548	71	273332	.029	.85	7.755
4	85.00	2315	5.02	20.00	6560	46.37	.050	.400	262947	3140	117895	141911	273814	471	271146	.033	.84	7.742
5	84.00	1890	3.86	20.00	6606	57.50	.050	.400	259807	251	117872	141684	273194	56	273000	.055	.84	7.671
6	83.90	1440	3.13	20.00	6606	75.07	.050	.400	259556	1719	117709	140128	273000	524	271806	.056	.84	7.655
7	83.00	1439	2.75	20.00	6606	75.12	.050	.400	257837	1885	117529	138421	271806	711	270629	.068	.83	7.632
8	82.00	1435	2.91	20.00	6606	75.33	.050	.400	255950	1562	117350	136738	270629	670	269437	.082	.83	7.599
9	81.00	1431	3.46	20.00	6536	74.74	.050	.400	252642	1944	116601	134197	269320	540	265016	.095	.82	7.558
10	80.00	1432	4.13	20.00	6536	74.71	.050	.400	250852	1824	116441	132547	265015	350	263543	.108	.82	7.521
11	79.00	1432	5.39	20.00	6536	74.71	.050	.400	249041	1983	116245	130910	263543	339	261900	.122	.81	7.479
12	77.90	1706	4.94	20.00	6570	63.03	.050	.400	279998	235	136263	143500	262066	43	261875	.136	.81	7.399
13	77.60	1941	5.83	20.00	6570	54.26	.050	.400	279763	2166	136032	141565	261875	322	260031	.138	.81	7.393
14	77.00	1941	5.96	20.00	6570	54.27	.050	.400	277597	2671	135744	139193	260031	403	257764	.153	.80	7.341
15	76.00	1941	5.08	20.00	6570	54.29	.050	.400	274927	2629	135456	136941	257764	519	255653	.171	.79	7.277
16	75.00	1950	5.23	20.00	6570	54.30	.050	.400	272297	2589	135169	134539	255653	515	253579	.190	.79	7.215
17	74.00	1950	5.50	20.00	6570	54.33	.150	.400	269709	2549	134883	132276	253579	494	251523	.205	.78	7.159
18	73.00	1980	4.97	20.00	6570	54.30	.350	.400	267159	2511	134597	130052	251523	582	249595	.226	.77	7.101
19	72.00	1961	4.75	20.00	6570	54.84	.050	.400	264649	493	134541	129615	249595	125	249227	.245	.77	7.047
20	71.50	1941	5.01	20.00	5570	55.39	.050	.400	264156	1336	134317	127902	249227	465	247755	.248	.77	7.036
21	71.00	1935	6.06	20.00	6570	55.56	.050	.400	262220	2381	134039	125900	247755	456	245930	.263	.76	6.995
22	70.00	1929	7.24	20.00	6500	55.14	.050	.400	259294	2349	132964	122371	245945	364	245901	.281	.76	6.931
23	69.00	1929	6.92	20.00	6500	55.14	.050	.400	255935	2314	132685	123934	245901	400	238936	.299	.75	6.875
24	68.00	1929	5.82	20.00	6500	55.14	.050	.400	253620	2280	132409	119331	238936	518	237224	.317	.74	6.820
25	67.00	1929	5.97	20.00	6500	55.14	.050	.400	251340	2246	132133	116961	237224	561	235535	.335	.74	6.770
26	66.00	1929	5.54	20.00	6500	55.14	.050	.400	249094	2213	131858	115023	235535	577	233902	.353	.73	6.722
27	65.00	2189	6.22	20.00	6500	45.62	.050	.400	246881	497	131795	114588	233902	113	233517	.372	.73	6.675
28	64.50	2446	7.90	20.00	6500	43.49	.050	.400	246383	2204	131516	112663	233517	376	231699	.376	.73	6.664
29	64.00	2446	7.36	20.00	6500	43.44	.050	.400	244179	2709	131169	110302	231699	519	229500	.394	.72	6.612
30	63.00	2446	6.62	20.00	6500	43.49	.050	.400	241470	2659	130822	107990	229500	615	227456	.417	.71	6.549
31	62.00	2446	6.89	20.00	6500	43.49	.050	.400	238811	2609	130476	105726	227456	594	225441	.440	.71	6.491
32	61.00	2447	8.20	20.00	6500	43.47	.050	.400	236202	2053	130200	103950	225441	383	223771	.463	.70	6.433
33	60.20	1928	6.83	20.00	6500	54.18	.050	.400	234149	380	130148	103621	223771	93	223684	.482	.70	6.386
34	60.00	1209	3.78	20.00	6430	87.05	.050	.400	232727	1258	129319	102152	223684	697	219950	.485	.69	6.362
35	59.00	1209	4.53	20.00	6430	87.06	.150	.400	271470	1246	129147	101077	219950	545	219279	.496	.69	6.346
36	58.00	1209	5.75	20.00	6430	87.03	.050	.400	230224	1235	128976	100013	219279	396	218440	.508	.69	6.326
37	57.00	1209	5.76	20.00	6430	87.03	.050	.400	228989	1223	128806	98960	218440	399	217616	.519	.69	6.301
38	56.00	1930	5.45	20.00	6430	85.57	.050	.400	227765	987	128667	99111	217616	320	216949	.531	.68	6.278
39	55.20	2284	7.51	20.00	6430	45.99	.020	0	226775	26	128641	98111	216949	106	217030	.540	.68	6.258
40	55.00	2615	7.35	20.00	6457	40.47	.020	0	226509	29	128594	98885	216878	124	216772	.545	.68	6.272
41	54.90	2115	5.11	20.00	6457	50.03	.020	0	226479	24	128570	98885	216772	165	216914	.550	.68	6.275
42	54.60	3487	5.86	20.00	6467	30.35	.020	0	226455	29	128540	98885	216914	169	216054	.554	.68	6.279
43	54.45	5137	9.56	20.00	6467	20.50	.020	0	226426	72	128465	98885	216054	214	216195	.558	.68	6.283
44	54.20	8462	15.89	20.00	6467	12.51	.020	0	226353	95	128373	98885	216195	146	216246	.571	.68	6.287
45	54.00	8059	13.81	20.00	6467	13.13	.020	0	226298	91	128282	98885	216246	165	216322	.587	.68	6.289
46	53.80	4597	5.85	20.00	6467	22.53	.020	0	226167	53	128229	98885	216322	244	216513	.602	.69	6.291
47	53.60	4631	5.64	20.00	6467	26.25	.020	0	226115	46	128184	98885	216513	270	216737	.611	.69	6.296
48	53.40	3194	5.43	20.30	6467	31.19	.020	0	226069	39	128145	98885	216737	240	216939	.618	.69	6.303
49	53.20	4551	9.13	20.53	6467	22.75	.020	0	226030	53	129091	98885	216939	162	217047	.625	.69	6.306
50	53.08	5502	11.58	20.70	6467	18.89	.021	0	227977	85	129026	98885	220047	142	220124	.634	.70	6.311
51	52.80	3539	10.35	20.90	6467	10.93	.021	0	227912	113	128914	98885	220124	150	220161	.644	.70	6.314
52	52.68	11363	21.61	21.00	6467	9.31	.021	0	227799	133	129780	98885	220161	132	220159	.662	.70	6.315
53	52.40	7553	14.37	21.00	6467	14.00	.021	0	227666	89	128692	98885	220159	144	220214	.684	.70	6.315
54	52.20	6164	9.20	21.00	6467	17.17	.021	0	227577	54	128637	98885	220214	143	220343	.698	.70	6.316
55	52.05	7124	9.62	21.00	6467	14.85	.021	0	227523	104	128533	98885	220343	284	220523	.707	.70	6.320
56	51.90	7395	11.18	21.00	6467	13.33	.021	0	227449	93	128470	98885	220525	204	220640	.724	.70	6.325
57	51.60	8074	10.41	21.00	6467	13.22	.021	0	227356	94	128376	98885	220640	218	220765	.739	.70	6.328
58	51.40	9350	11.82	21.00	6467	11.32	.021	0	227262	219	128159	98885	220765	453	221000	.754	.71	6.332
59	51.00	12629	14.22	21.00	6467	8.38	.021	0	227043	147	128010	98885	221000	241	221093	.789	.71	6.339
60	50.85	11763	14.15	21.00	6467	9.00	.021	0	226896	103	127908	98885	221093	169	221160	.813	.71	6.341
61	50.65	8175	11.94	21.00	6467	12.95	.021	0	226793	71	127836	98885	221160	146	221235	.830	.71	6.343
62	50.50	7601	10.49	21.00	6467	13.92	.021	0	227386	44	125022	99320	221257	101	221314	.841	.71	6.345
63	50.40	10561	15.45	21.00	6469	10.02	.021	0	227342	123	127699	99320	221314	176	221367	.849	.71	6.347
64	50.20	11474	21.21	21.00	6469	8.91	.021	0	227219	138	127761	99320	221367	139	221367	.868	.71	6.348
65	50.00	10799	21.73	21.00	6398	9.69	.021	0	226269	127	127115	99027	218445	123	218451	.891	.70	6.334
66	49.80	12322	23.79	21.00	6412	8.52	.021	0	238167	157	138982	99027	218526	128	218796	.912	.70	6.330
67	49.60	11914	22.91	21.00	6412	8.01	.021	0	238009	152	138830	99027	218796	128	218772	.935	.70	6.329

REACH	MILE PT	XSEC SQFT	DEPTH FT	TEMP C	Q CFS	VEL MPD	KC BASE	KN 10	INITIAL	SATIS-FIED	FINAL CARB	NITR	INITIAL	REAER	FINAL	TIME DAYS	PCT SAT	PPM
68	49.45	10591	21.20	21.00	6412	9.91	.021	0	237857	135	138695	99027	218772	125	218762	.958	.70	6.329
69	49.20	12057	22.25	21.00	6412	8.70	.021	0	237722	154	138541	99027	218762	134	218743	.978	.70	6.328
70	49.00	14147	24.00	21.00	6412	7.42	.021	0	237568	180	138361	99027	218743	145	218707	1.001	.70	6.323
71	48.80	12705	24.90	21.00	6412	8.26	.021	0	237388	161	138199	99027	218707	125	218670	1.028	.70	6.327
72	48.60	10477	22.05	21.00	6412	10.02	.021	0	237227	133	138066	99027	218670	118	218655	1.052	.70	6.326
73	48.40	9993	18.21	21.00	6412	10.61	.021	0	237094	125	137941	99027	218655	140	218670	1.072	.70	6.325
74	48.20	10205	16.39	21.00	6412	10.29	.021	0	236968	129	137812	99027	218670	164	218704	1.091	.78	6.326
75	48.00	10258	15.56	21.00	6412	10.23	.021	0	236839	162	137649	99027	218704	220	218762	1.110	.70	6.327
76	47.75	9956	15.83	21.00	6412	10.54	.021	0	236677	94	137555	99027	218762	125	218792	1.135	.70	6.325
77	47.60	10450	16.05	21.00	6412	10.04	.021	0	236582	132	137423	99027	218792	172	218832	1.149	.70	6.329
78	47.40	12111	19.51	21.00	6412	8.66	.021	0	236450	153	137270	99027	218832	157	218836	1.169	.70	6.330
79	47.20	12940	22.90	21.00	6412	8.11	.021	0	236297	163	137107	99027	218836	139	218813	1.192	.70	6.330
80	47.00	12084	23.31	21.00	6412	8.65	.021	0	236134	152	136955	99027	218813	128	218788	1.217	.70	6.330
81	46.80	12719	24.02	21.00	6412	8.25	.021	0	235982	200	136755	99027	218788	162	218750	1.240	.70	6.329
82	46.55	14561	24.57	21.00	6412	7.21	.021	0	235782	137	136617	99027	218750	107	218720	1.270	.70	6.328
83	46.40	14637	23.50	21.00	6412	7.17	.021	0	235645	184	136434	99027	218720	153	218690	1.291	.70	6.327
84	46.20	16531	25.43	21.00	6412	6.35	.021	0	235461	207	136227	99027	218690	158	218641	1.319	.70	6.326
85	46.00	19305	3.95	21.10	6412	5.44	.021	0	235254	182	136045	99027	218641	111	218571	1.350	.70	6.325
86	45.95	17493	24.03	21.30	6412	6.00	.021	0	235072	277	135768	99027	218570	187	218480	1.378	.71	6.323
87	45.60	13915	25.04	21.50	6412	7.54	.021	0	234795	178	135590	99027	218480	134	218437	1.420	.71	6.320
88	45.40	14556	24.81	21.70	6412	7.21	.022	0	234618	187	135403	99027	218437	141	218391	1.446	.71	6.319
89	45.20	15383	20.54	21.90	6412	6.82	.022	0	234430	199	135204	99027	218391	185	218376	1.474	.71	6.317
90	45.00	13579	21.64	22.00	6412	7.73	.022	0	234231	221	134983	99027	218376	191	218347	1.503	.72	6.317
91	44.75	14518	26.59	22.03	6412	7.23	.022	0	234010	188	134795	99027	218347	130	218288	1.535	.72	6.316
92	44.55	16006	27.84	22.50	6412	6.56	.022	0	233822	156	134639	99027	218288	102	218234	1.563	.72	6.315
93	44.40	16594	27.35	22.00	6412	6.21	.022	0	233666	219	134420	99027	218234	146	218162	1.586	.72	6.313
94	44.20	17497	29.39	22.00	6412	6.00	.022	0	233448	170	134251	99027	218162	109	218101	1.618	.72	6.311
95	44.05	17487	30.41	22.00	6412	6.00	.022	0	233278	202	133969	99027	218101	169	217988	1.643	.72	6.309
96	43.80	17582	30.53	22.00	6412	5.97	.022	0	232996	226	133742	99027	217988	135	217896	1.685	.72	6.306
97	43.60	16975	27.59	22.00	6412	6.22	.022	0	232769	217	133525	99027	217896	145	217825	1.718	.72	6.303
98	43.40	16403	27.47	22.00	6412	6.24	.022	0	232552	216	133309	99027	217825	145	217754	1.751	.72	6.301
99	43.20	15351	26.75	22.00	6412	6.63	.022	0	232337	197	133113	99027	217754	137	217695	1.783	.72	6.299
100	43.00	16891	29.41	22.00	6412	6.21	.022	0	232140	216	132896	99027	217695	136	217614	1.812	.72	6.297
101	42.80	19172	29.32	22.00	6412	5.77	.022	0	231924	232	132664	99027	217614	147	217529	1.844	.72	6.295
102	42.60	14944	23.76	22.00	6412	7.02	.022	0	231692	191	132474	99027	217529	153	217467	1.879	.71	6.293
103	42.40	15255	27.05	22.00	6412	6.85	.022	0	231501	194	132279	99027	217467	135	217432	1.907	.71	6.291
104	42.20	14738	25.21	22.00	6412	7.12	.022	0	231307	187	132092	99027	217432	141	217385	1.936	.71	6.290
105	42.00	15031	24.04	22.00	6412	6.95	.022	0	231165	191	131921	99053	217387	152	217347	1.964	.71	6.288
106	41.80	16480	25.85	22.00	6412	6.37	.022	0	230974	209	131712	99053	217347	136	217274	1.993	.71	6.287
107	41.60	14543	25.67	22.00	6412	7.21	.022	0	230765	184	131528	99053	217274	131	217221	2.024	.71	6.285
108	41.40	15726	24.90	22.00	6412	6.67	.022	0	230581	199	131329	99053	217221	153	217175	2.052	.71	6.284
109	41.20	16974	24.62	22.00	6412	6.22	.022	0	230382	213	131146	99053	217175	166	217128	2.082	.71	6.282
110	41.00	14345	21.54	22.00	6412	7.31	.022	0	230169	181	130935	99053	217128	165	217112	2.114	.71	6.281
111	40.80	13781	21.73	22.00	6412	7.61	.022	0	229988	174	130761	99053	217112	157	217096	2.142	.71	6.280
112	40.60	15900	26.11	22.00	6412	6.60	.022	0	229815	200	130561	99053	217096	147	217043	2.168	.71	6.280
113	40.40	16005	26.29	22.00	6412	6.55	.022	0	229615	201	130360	99053	217043	147	216949	2.198	.71	6.278
114	40.20	14076	22.36	22.00	6412	7.45	.022	0	229420	176	130196	99057	216949	155	216968	2.229	.71	6.277
115	40.00	15055	25.11	22.00	6342	6.83	.022	0	229414	190	129645	99739	214145	145	214130	2.256	.71	6.263
116	39.80	15552	27.27	22.00	6342	6.55	.022	0	228339	200	129325	99304	214104	141	214045	2.285	.71	6.262
117	39.60	14489	23.83	22.00	6342	7.16	.022	0	228129	182	129143	99304	214045	150	214012	2.315	.71	6.260
118	39.40	13471	21.52	22.00	6342	7.70	.022	0	227947	127	129016	99304	214012	117	214003	2.343	.71	6.259
119	39.25	13287	21.43	22.00	6342	7.81	.022	0	227820	208	128808	99304	214003	194	213948	2.363	.71	6.259
120	39.00	12842	21.37	22.00	6342	8.21	.022	0	227897	198	128660	99049	213994	180	213976	2.395	.71	6.258
121	38.75	11628	18.24	22.00	6342	7.74	.022	0	227424	126	128524	99049	213976	107	213957	2.425	.71	6.257
122	38.60	16347	28.99	22.00	6342	6.16	.022	0	227573	210	128314	99049	213957	152	213899	2.444	.71	6.257
123	38.40	17951	32.03	22.00	6342	5.78	.022	0	227363	224	128090	99049	213899	143	213818	2.477	.71	6.255
124	38.20	17172	30.67	22.00	6342	6.04	.022	0	227139	214	127876	99049	213818	134	213739	2.511	.71	6.253
125	38.00	17529	31.32	22.10	6342	5.92	.022	0	226925	219	127657	99049	213739	134	213653	2.545	.71	6.251
126	37.80	17769	29.85	22.30	6342	5.84	.022	0	226706	224	127434	99049	213653	142	213572	2.578	.71	6.248
127	37.60	17552	26.04	22.50	6342	5.91	.022	0	226483	222	127211	99049	213572	163	213513	2.613	.72	6.246
128	37.40	16692	24.01	22.70	6342	6.22	.023	0	226260	213	126998	99049	213513	169	213469	2.646	.72	6.244
129	37.20	15328	22.57	22.90	6342	6.77	.023	0	226047	197	126801	99049	213469	163	213435	2.679	.72	6.243
130	37.00	14265	21.95	23.00	6342	7.28	.023	0	225850	184	126627	99049	213435	159	213410	2.708	.72	6.242
131	36.80	15093	24.00	23.00	6342	6.85	.023	0	225666	194	126422	99049	213410	152	213367	2.736	.72	6.241
132	36.65	16406	25.92	23.00	6342	6.33	.023	0	225471	211	126211	99049	213367	151	213307	2.765	.72	6.240
133	36.40	16220	23.61	23.00	6342	6.40	.023	0	225260	208	126003	99049	213307	167	213265	2.796	.72	6.238
134	36.20	16835	27.97	23.00	6342	6.16	.023	0	225052	216	125787	99049	213265	143	213192	2.828	.72	6.237
135	36.00	16208	29.29	23.00	6342	6.40	.023	0	224836	259	125528	99049	213192	164	213097	2.860	.72	6.235
136	35.75	12913	22.01	23.00	6419	8.13	.023	0	226333	123	126280	99935	216659	107	216659	2.899	.73	6.261
137	35.60	13725	22.41	23.00	6419	7.65	.023	0	226215	131	126025	99935	216659	117	216646	2.918	.73	6.260
138	35.45	15125	22.55	23.00	6419	6.95	.023	0	226084	240	125910	99935	216646	199	216606	2.937	.73	6.260
139	35.20	15199	27.08	23.00	6419	6.91	.023	0	225844	192	125717	99935	216606	133	216546	2.973	.73	6.259
140	35.00	18205	31.67	23.00	6419	5.77	.023	0	225652	230	125497	99935	216546	134	216449	3.002	.73	6.257
141	34.80	18241	26.95	23.00	6419	5.76	.023	0	225422	230	125257	99935	216449	161	216380	3.037	.73	6.254

128

TABLE B-24 (continued)

REACH	MILE PT	XSEC SQFT	DEPTH FT	TEMP C	Q CFS	VEL MPD	KC BASE 10	KN	INITIAL	SATIS-FIED	FINAL CARB	NITR	INITIAL	REAER	FINAL	TIME DAYS	PCT SAT	PPM
142	34.60	15091	19.76	23.00	6419	6.97	.023	0	225192	190	125067	99935	216380	189	216380	3.071	.73	6.252
143	34.40	17788	27.67	23.00	6419	5.91	.023	0	225002	157	124910	99935	216380	106	216329	3.100	.73	6.252
144	34.25	19665	31.35	23.00	6419	5.34	.023	0	224845	74	124836	99935	216329	44	216299	3.124	.72	6.251
145	34.20	24453	31.20	23.00	6419	4.23	.023	0	224771	312	124524	99935	216299	186	216174	3.135	.72	6.250
146	34.00	24439	33.82	23.00	6419	4.30	.023	0	224459	306	124219	99935	216174	168	216035	3.182	.72	6.246
147	33.80	15358	26.14	23.00	6419	6.84	.023	0	224153	192	124027	99935	216035	136	215940	3.229	.73	6.240
148	33.60	10920	16.74	23.00	6419	9.62	.023	0	223961	204	123822	99935	215940	253	216023	3.258	.73	6.242
149	33.30	12720	13.71	23.00	6419	8.26	.023	0	223757	198	123624	99935	216023	314	216145	3.289	.72	6.245
150	33.05	17055	17.44	23.00	6419	6.16	.023	0	223559	53	123571	99935	216145	62	216154	3.320	.72	6.245
151	33.00	15516	16.99	23.00	6420	6.77	.023	0	223694	193	123521	100180	216165	234	216208	3.328	.72	6.245
152	32.80	13645	16.74	23.00	6420	7.70	.023	0	223701	169	123351	100180	216205	210	216248	3.357	.72	6.247
153	32.60	20043	25.06	23.00	6420	5.24	.023	0	223531	186	123165	100180	216248	144	216205	3.383	.72	6.246
154	32.45	26513	42.77	23.00	6420	3.92	.023	0	223345	83	123082	100180	216205	35	216157	3.412	.72	6.246
155	32.40	21704	37.95	23.00	6420	4.84	.023	0	223262	201	122880	100180	216157	98	216054	3.425	.72	6.245
156	32.25	11740	15.41	23.00	6420	8.95	.023	0	223060	145	122735	100180	216054	200	216109	3.456	.72	6.242
157	32.05	8651	9.60	23.00	6420	12.14	.023	0	222915	133	122602	100180	216109	340	216315	3.478	.72	6.244
158	31.80	16336	17.55	23.00	6420	6.43	.023	0	222782	201	122400	100180	216315	231	216346	3.499	.72	6.250
159	31.60	20751	27.94	23.00	6420	5.06	.023	0	222616	230	122181	100206	216347	158	216275	3.530	.72	6.251
160	31.42	26601	37.41	23.00	6420	3.95	.023	0	222386	359	121821	100206	216275	179	216095	3.565	.72	6.248
161	31.20	26185	33.57	23.00	6420	4.01	.023	0	222027	321	121501	100206	216095	181	215956	3.621	.72	6.243
162	31.00	21397	29.65	23.00	6420	4.91	.023	0	221706	261	121240	100206	215956	170	215464	3.671	.72	6.239
163	30.80	17263	22.29	23.00	6420	6.11	.023	0	221445	252	120988	100206	215864	227	215927	3.712	.72	6.237
164	30.56	9788	15.39	23.00	6420	10.73	.023	0	221194	214	120774	100206	215840	302	215927	3.751	.72	6.236
165	30.20	13157	35.72	23.00	6420	7.99	.023	0	220979	160	120614	100206	215927	78	215845	3.784	.72	6.236
166	30.00	14750	38.76	23.00	6420	7.12	.023	0	220819	179	120220	100206	215845	57	215753	3.809	.72	6.233
167	29.88	17768	19.58	23.00	6420	5.91	.023	0	220641	215	120220	100206	215753	227	215766	3.838	.72	6.234
168	29.60	24705	20.92	23.00	6420	4.25	.023	0	220425	298	119921	100206	215766	292	215760	3.871	.72	6.234
169	29.40	25320	22.97	23.00	6420	4.05	.023	0	220127	312	119609	100206	215760	275	215722	3.918	.72	6.232
170	29.20	23375	19.47	23.00	6420	4.40	.023	0	219815	287	119322	100206	215722	308	215743	3.965	.72	6.233
171	29.00	19672	15.70	23.00	6420	5.34	.023	0	219528	118	119204	100206	215743	165	215790	4.013	.72	6.234
172	28.90	19902	16.73	23.00	6420	5.26	.023	0	219410	299	118905	100206	215790	386	215897	4.032	.72	6.237
173	28.65	27745	30.36	23.00	6420	3.79	.023	0	219110	331	118573	100206	215877	215	215761	4.079	.72	6.242
174	28.45	32135	42.01	23.00	6456	3.29	.023	0	225667	198	123251	102218	217267	86	217154	4.132	.72	6.239
175	28.35	30338	39.93	23.00	6456	3.44	.023	0	225469	374	122877	102218	217154	172	216953	4.163	.72	6.235
176	28.15	30062	35.67	23.00	6456	3.52	.023	0	225095	240	122635	102218	216953	127	216840	4.220	.72	6.230
177	28.02	31073	33.24	23.00	6456	3.40	.023	0	224856	34	122599	102218	216840	22	216824	4.257	.72	6.223
178	28.00	30317	31.53	23.00	6479	3.50	.023	0	232833	276	130339	102218	217356	159	217239	4.263	.72	6.223
179	27.86	29836	30.59	23.00	6479	3.55	.023	0	232557	116	130223	102218	217239	69	217192	4.303	.72	6.219
180	27.80	30495	31.50	23.00	6479	3.48	.023	0	232627	396	129898	102334	217199	237	217041	4.320	.72	6.207
181	27.60	30421	31.78	23.00	6500	3.50	.023	0	248264	441	145489	102334	217526	227	217313	4.377	.72	6.201
182	27.40	28709	35.13	23.00	6500	3.71	.023	0	247823	415	145075	102334	217313	192	217091	4.435	.72	6.195
183	27.20	28780	32.43	23.00	6500	3.70	.023	0	247409	414	144660	102334	217091	211	216887	4.489	.72	6.199
184	27.00	16337	13.07	23.00	6500	6.51	.023	0	246994	12	144649	102334	216887	11	216887	4.543	.72	6.189
185	26.99	2003	16.33	23.00	6500	53.19	.023	0	246993	66	144582	102334	231339	128	231401	4.544	.77	6.603
186	26.53	6956	19.99	23.00	6500	15.20	.023	0	246916	5	144577	102334	231401	4	231400	4.553	.77	6.603
187	26.52	10675	32.65	23.05	6500	9.95	.023	0	246911	115	144462	102334	231400	56	231341	4.569	.77	6.601
188	26.37	15470	44.39	23.15	6500	6.85	.023	0	246796	190	144272	102334	231341	63	231214	4.585	.77	6.598
189	26.20	16466	40.22	23.25	6500	6.46	.023	0	246606	239	144034	102334	231214	90	231065	4.593	.77	6.593
190	26.00	12436	26.67	23.35	6500	8.55	.023	0	246368	235	143799	102334	231065	189	231020	4.624	.77	6.592
191	25.74	13011	18.45	23.45	6500	8.18	.023	0	246133	171	143628	102334	231020	157	231005	4.655	.77	6.592
192	25.56	9351	16.52	23.50	6500	12.74	.023	0	245962	116	143512	102334	231005	121	231011	4.677	.77	6.592
193	25.37	4537	11.63	23.50	6500	23.45	.023	0	245846	53	143459	102334	231011	87	231045	4.692	.77	6.592
194	25.21	4635	11.23	23.50	6504	22.95	.023	0	248219	71	144029	104119	231133	122	231184	4.698	.77	6.592
195	25.00	5074	12.59	23.50	6504	20.99	.023	0	248148	67	143962	104119	231184	95	231211	4.708	.77	6.593
196	24.82	6475	13.02	23.50	7357	16.59	.023	0	254275	104	149250	104708	268892	145	268933	4.716	.79	6.779
197	24.54	13221	17.71	23.50	7357	9.11	.023	0	254171	213	149463	104708	268933	201	268921	4.729	.79	6.780
198	24.34	15413	20.25	23.50	7357	7.41	.023	0	253958	207	149044	104708	268921	166	268891	4.755	.79	6.780
199	24.14	13979	20.78	23.50	7358	8.61	.023	0	254267	131	149175	104961	268897	102	268770	4.781	.79	6.775
200	24.00	19152	23.40	23.50	7358	6.29	.023	0	254136	205	148970	104961	268868	108	268770	4.797	.79	6.776
201	23.84	17226	26.10	23.50	7358	6.99	.023	0	253931	173	148797	104961	268770	104	268701	4.844	.79	6.774
202	23.69	12379	19.52	23.50	7358	9.73	.023	0	253758	132	148665	104961	268701	112	268681	4.861	.79	6.773
203	23.53	12493	21.96	23.50	7358	9.65	.023	0	253626	208	148457	104961	268641	153	268626	4.896	.79	6.773
204	23.24	17062	23.55	23.50	7358	7.06	.023	0	253418	318	148139	104961	268626	217	268525	4.926	.79	6.773
205	23.00	14435	19.36	23.50	7358	8.35	.023	0	253100	211	147928	104961	268525	181	268495	4.952	.79	6.769
206	22.75	8935	25.87	23.50	7358	13.44	.023	0	252899	101	147827	104961	268495	62	268367	4.965	.79	6.768
207	22.61	14555	37.89	23.50	7358	8.57	.023	0	252734	149	147678	104961	268367	60	268240	4.964	.79	6.765
208	22.45	17552	33.65	23.50	7358	6.85	.023	0	252639	210	147468	104961	268240	82	267530	5.010	.79	6.762
209	22.27	21573	49.42	23.50	7358	5.56	.023	0	252429	573	146895	104961	267852	163	267697	5.082	.79	6.752
210	22.17	19436	46.47	23.50	7359	6.07	.023	0	252243	248	146676	105318	267697	93	267607	5.113	.79	6.745
211	21.65	13860	29.05	23.50	7359	8.69	.023	0	251995	201	146476	105318	267607	110	267262	5.139	.79	6.745
212	21.45	27269	65.81	23.50	7359	4.42	.023	0	251794	412	146061	105318	267262	67	266626	5.191	.79	6.737
213	21.23	30933	69.71	23.50	7359	3.89	.023	0	251382	749	145315	105318	266626	112	266648	5.286	.79	6.721
214	20.85	23997	42.12	23.50	7359	5.02	.023	0	250633	282	145034	105318	266626	104	266260	5.322	.79	6.716
215	20.68	26735	46.45	23.50	7359	4.50	.023	0	250352	273	144755	105318	266448	90	266260	5.322	.79	6.716

TABLE B-24 (continued)

REACH	MILE PT	XSEC SQFT	DEPTH FT	TEMP C	Q CFS	VEL MPD	KC BASE 10	KN	INITIAL	SATIS-FIED	FINAL CARB	FINAL NITR	INITIAL	REAER	FINAL	TIME DAYS	PCT SAT	PPM
216	20.52	26703	49.41	23.50	7359	4.51	.023	0	250073	503	144253	105318	266260	148	265936	5.357	.79	6.711
217	20.23	27374	44.72	23.50	7365	4.40	.023	0	253039	586	144365	108087	266043	203	265659	5.421	.79	6.700
218	19.90	30110	38.95	23.50	7367	4.00	.023	0	254726	255	145162	109309	265720	155	265570	5.496	.78	6.690
219	19.77	36315	48.05	23.50	7367	3.32	.023	0	264471	472	144690	109309	265570	149	265246	5.529	.78	6.686
220	19.57	37831	50.41	23.50	7367	3.19	.023	0	263999	417	144273	109309	265246	123	264953	5.589	.78	6.678
221	19.40	40306	55.69	23.50	7367	2.99	.023	0	253582	677	143597	109309	264953	171	264447	5.642	.78	6.671
222	19.14	32790	55.07	23.50	7367	3.64	.023	0	252905	295	143301	109309	264447	77	264228	5.729	.78	6.658
223	19.00	30065	41.65	23.50	7367	4.01	.023	0	252610	270	143031	109309	264228	106	264064	5.767	.78	6.652
224	18.86	46974	46.30	23.50	7367	2.57	.023	0	252340	540	142491	109309	264064	136	263709	5.802	.78	6.645
225	18.68	49448	48.01	23.50	7367	2.44	.023	0	251799	568	141923	109309	263709	187	263329	5.872	.78	6.639
226	18.50	45049	47.52	23.50	7367	2.68	.023	0	261231	287	141636	109309	263329	97	263139	5.946	.78	6.630
227	18.40	45049	47.52	23.50	7368	2.68	.023	0	261059	29	141636	109395	263176	10	263157	5.954	.78	6.625
228	18.39	40650	46.85	23.50	7371	2.97	.023	0	252652	78	141959	110616	263217	27	263166	5.987	.78	6.624
229	18.36	32765	40.41	23.50	7371	3.64	.023	0	252575	396	141563	110616	263166	166	262936	5.997	.78	6.622
230	18.17	28939	34.86	23.50	7371	4.19	.023	0	262179	128	141435	110616	262936	64	262872	6.049	.78	6.617
231	18.10	30401	41.01	23.50	7371	3.97	.023	0	252051	347	141098	110616	262872	144	262669	6.066	.78	6.615
232	17.92	33564	45.64	23.50	7371	3.59	.023	0	251704	403	140685	110616	262669	142	262408	6.111	.77	6.610
233	17.73	32906	45.64	23.50	7371	3.67	.023	0	251301	394	140292	110616	262405	144	262158	6.164	.77	6.603
234	17.54	35630	44.96	23.50	7371	3.39	.023	0	250908	425	139866	110616	262158	141	261874	6.216	.77	6.597
235	17.35	44672	52.17	23.50	7371	2.70	.023	0	250482	531	139335	110616	261874	161	261504	6.272	.77	6.590
236	17.16	56410	54.94	23.50	7371	2.14	.023	0	249951	211	139124	110616	261504	59	261352	6.342	.77	6.581
237	17.10	53026	46.42	23.50	7371	2.27	.023	0	249740	792	138332	110616	261352	290	260851	6.370	.77	6.577
238	16.86	33523	29.85	23.50	7371	3.57	.023	0	248948	377	137955	110616	260851	236	260709	6.476	.77	6.564
239	16.65	38992	40.09	23.50	7371	3.09	.023	0	248571	602	137353	110616	260709	271	260378	6.526	.77	6.561
240	16.43	42376	49.70	23.50	7371	2.85	.023	0	247969	703	136651	110616	260378	239	259915	6.607	.77	6.552
241	16.16	31539	34.56	23.50	7371	3.82	.023	0	247266	309	136342	110616	259915	168	259774	6.702	.77	6.541
242	16.00	34177	24.72	23.50	7371	3.53	.023	0	246959	376	135966	110616	259774	299	259697	6.744	.77	6.537
243	15.82	145114	83.54	23.50	7371	.83	.023	0	246582	2194	133772	110616	259697	248	257752	6.795	.77	6.535
244	15.57	143644	85.58	23.50	7371	.84	.023	0	244388	1542	132236	110616	257752	169	256378	7.096	.76	6.486
245	15.39	33849	28.14	23.50	7371	3.56	.023	0	242846	361	131889	110616	256378	252	256249	7.310	.76	6.452
246	15.22	32313	28.25	23.50	7371	3.73	.023	0	242505	229	131660	110616	256249	169	256229	7.358	.76	6.449
247	15.10	25802	27.25	23.50	7371	4.67	.023	0	242276	487	131174	110616	256229	375	256119	7.390	.76	6.445
248	14.74	22527	29.53	23.50	7371	5.35	.023	0	241790	344	130830	110616	256119	244	256018	7.458	.76	6.445
249	14.52	27366	39.73	23.50	7371	4.41	.023	0	241446	273	130557	110616	256018	138	255393	7.507	.75	6.443
250	14.35	28201	41.23	23.50	7371	4.28	.023	0	241173	280	130277	110616	255393	136	254739	7.546	.75	6.439
251	14.15	34175	31.74	23.50	7371	3.53	.023	0	240893	359	129918	110616	255739	237	255617	7.585	.75	6.436
252	14.00	44972	31.62	23.50	7371	2.64	.023	0	240534	471	129447	110616	255617	314	255460	7.636	.75	6.432
253	13.82	43390	33.53	23.50	7371	2.75	.023	0	240063	635	129812	110616	255460	398	255223	7.703	.75	6.423
254	13.57	39139	30.54	23.50	7371	3.03	.023	0	239428	361	129451	110616	255223	253	255115	7.794	.75	6.423
255	13.41	40544	29.54	23.50	7371	2.97	.023	0	239067	443	129008	110616	255115	324	254996	7.846	.75	6.420
256	13.22	43770	33.43	23.50	7371	2.76	.023	0	238624	552	127456	110616	254996	353	254798	7.910	.75	6.417
257	13.00	41272	37.75	23.50	7371	2.92	.023	0	238072	377	127079	110616	254798	211	254633	7.990	.75	6.412
258	12.84	36697	40.43	23.50	7371	3.23	.023	0	243695	6563	126515	110616	254633	304	254373	9.045	.75	6.405
259	12.57	36365	44.22	23.50	7371	3.32	.023	0	237132	227	126289	110616	249373	113	243260	9.127	.73	6.250
260	12.46	41649	44.39	23.50	7371	2.90	.023	0	236905	541	125748	110616	248260	271	247989	9.160	.73	6.247
261	12.23	45933	49.61	23.50	7371	2.63	.023	0	236364	594	125154	110616	247989	256	247651	9.239	.73	6.242
262	12.00	41123	52.40	23.50	7371	2.93	.023	0	235770	530	124624	110616	247651	211	247333	9.327	.73	6.232
263	11.77	34652	44.94	23.50	7371	3.12	.023	0	235240	367	124259	110616	247333	185	247150	9.405	.73	6.224
264	11.60	47478	41.75	23.50	7371	2.54	.023	0	234873	528	123730	110616	247150	294	246916	9.460	.73	6.219
265	11.40	51650	42.16	23.50	7371	2.34	.023	0	234345	572	123158	110616	246916	317	246661	9.539	.73	6.213
266	11.20	50588	44.15	23.50	7371	2.34	.023	0	233774	557	122560	110616	246661	293	246397	9.624	.73	6.207
267	11.00	54726	48.51	23.50	7371	2.20	.023	0	233216	810	121701	110616	246397	377	245964	9.708	.73	6.200
268	10.73	55166	47.34	23.50	7371	2.19	.023	0	232407	391	121450	110616	245964	187	245760	9.831	.73	6.184
269	10.60	62157	45.75	23.50	7371	2.31	.023	0	232016	567	120833	110616	245760	291	245485	9.890	.72	6.184
270	10.40	61929	44.52	23.50	7371	2.32	.023	0	231449	561	120272	110616	245485	301	245224	9.977	.72	6.171
271	10.20	63926	43.75	23.50	7371	1.89	.023	0	230888	688	119594	110616	245224	381	244917	10.063	.72	6.177
272	10.00	74074	38.64	23.50	7371	1.54	.023	0	230200	834	116750	110616	244917	544	244627	9.169	.72	6.163
273	9.80	70279	34.93	23.50	7371	1.72	.023	0	229366	746	114034	110616	244627	553	244434	9.298	.72	6.156
274	9.60	58683	36.59	23.50	7371	2.06	.023	0	228620	619	117384	110616	244434	447	244262	9.415	.72	6.151
275	9.40	60313	36.54	23.50	7371	2.00	.023	0	228000	633	116751	110616	244262	451	244080	9.512	.72	6.147
276	9.20	71444	42.22	23.50	7371	1.69	.023	0	233367	6746	116006	110616	244080	465	237799	9.612	.72	6.142
277	9.00	65655	45.94	23.50	7371	1.41	.023	0	226622	888	115119	110616	237799	516	237427	9.731	.70	5.998
278	8.80	93555	45.44	23.50	7371	1.29	.023	0	225734	962	114156	110616	237427	620	237046	9.873	.70	5.975
279	8.60	94293	40.92	23.50	7371	1.28	.023	0	224772	961	113195	110616	237046	664	236783	10.028	.70	5.966
280	8.40	83983	44.52	23.50	7371	1.36	.023	0	223811	785	112430	110616	236783	475	230499	10.184	.70	5.959
281	8.23	104700	54.25	23.50	7371	1.15	.023	0	229046	7726	110701	110616	236499	954	229724	10.309	.70	5.951
282	7.90	124733	49.54	23.50	7371	.94	.023	0	221317	637	110064	110616	229724	375	229462	10.596	.68	5.781
283	7.80	119397	44.12	23.50	7371	1.01	.023	0	220680	1171	108993	110616	229462	821	229112	10.703	.68	5.774
284	7.60	64516	42.77	23.50	7371	1.23	.023	0	219509	956	107937	110616	229112	706	228862	10.901	.68	5.765
285	7.40	87743	43.20	23.50	7371	1.37	.023	0	218553	846	137091	110616	228862	623	228619	11.065	.67	5.759
286	7.29	74245	41.82	23.50	7428	1.55	.023	0	218352	743	106349	111261	230614	579	230450	11.209	.67	5.759
287	7.00	64504	41.70	23.50	7428	1.54	.023	0	220615	439	108915	111261	230497	336	230355	11.333	.67	5.754
288	6.86	53434	42.91	23.50	7428	2.05	.023	0	220176	746	108419	111261	230355	555	230163	11.412	.67	5.752
289	6.60	59263	42.62	23.50	7428	2.05	.023	0	219430	569	107600	111261	230163	430	230025	11.539	.67	5.747

130

TABLE B-24 (continued)

REACH	MILE PT	XSEC SQFT	DEPTH FT	TEMP C	Q CFS	VEL MPD	KC BASE 10	KN	INITIAL	SATIS-FIED	FINAL CARB	NITR	INITIAL	REAER	FINAL	TIME DAYS	PCT SAT	PPM
290	6.40	56120	41.49	23.50	7428	2.17	.023	0	218861	536	107064	111261	233025	422	229911	11.637	.67	5.744
291	6.20	59925	42.15	23.50	7428	2.03	.023		224325	6569	106495	111261	229911	454	223795	11.729	.67	5.741
292	6.00	58393	43.15	23.50	7428	2.04	.023	0	217756	552	105943	111261	223795	441	223634	11.828	.65	5.585
293	5.80	53672	42.45	23.50	7428	2.26	.023	0	217204	505	105438	111261	223634	414	223593	11.924	.65	5.585
294	5.60	55606	42.62	23.50	7428	2.19	.023		216699	520	104918	111261	223593	427	223499	12.012	.65	5.583
295	5.40	59134	44.95	23.50	7428	2.06	.023		216178	551	104367	111261	223499	424	223373	12.104	.65	5.581
296	5.20	64913	45.73	23.50	7428	1.87	.023		221628	6601	103766	111261	223373	467	217239	12.201	.65	5.578
297	5.00				7428				215027				217239			12.308	.64	5.424

APPENDIX C

THE VELZ ALGORITHM

The Velz model of stream reaeration is employed in the routine WILMA. This estimation of atmospheric reaeration in stream flow is defined by Equations 11 to 18. Further discussion may be found in Velz's text (28).

R = Atmospheric reaeration in reach, ppd

$$= QS \left[P_{bottom} - P_{top} \right] \times 10^{-6} + \left[\begin{array}{c} BOD \\ IOD \\ exerted \end{array} \right] \tag{11}$$

$$= Y \left[1 - (P_{top} + P_{bottom})/2 \right] \tag{12}$$

Y = Reaeration in reach initially devoid of DO, ppd

$$= \left[\begin{array}{c} DO \text{ in} \\ saturated \\ reach, \text{ lb} \end{array} \right] \left[\begin{array}{c} D \end{array} \right] \left[\begin{array}{c} Mix \\ intervals \\ per \text{ day} \end{array} \right]$$

$$= 62.4 \text{ VS} \times 10^{-6} \times D \times 1440/I \tag{13}$$

D = Reaeration as percentage saturation absorbed
    per mix interval by water initially devoid of DO

$$= \frac{2}{30.48 \text{ H}} \left[\frac{a \text{ I}}{\pi \ 60} \right]^{\frac{1}{2}}, \text{ Deininger's solution} \tag{14}$$

a = Phelps' diffusion coefficient

$$= 1.42 \times 1.1^{(T-20)} \tag{15}$$

I = Mix interval in reach, minutes

$$= 1.797 + 3.090 \text{ H} - 0.088 \text{ H}^2 + 0.00092 \text{ H}^3,$$
$$\text{usual freshwater streams} \tag{16}$$

$$= 1.426 + 2.215 \text{ H} - 0.061 \text{ H}^2 + 0.00063 \text{ H}^3,$$
$$\text{tidal regimes} \tag{17}$$

$$R = 5.12 \times 10^{-4} \times 1.1^{(T/2-10)} \text{ VS} \left[1-(P_{top} + P_{bottom})/2 \right]$$
$$/(HI^{\frac{1}{2}}) \tag{18}$$

132

where   Q = Discharge through reach, lbs/day water
                    S = DO saturation, mg/l
                    P = Percent DO saturation as decimal
                    V = Reach volume, ft^3
                    H = Reach depth, ft
                    T = Reach temperature, °C

Equations 16 and 17 are empirical determinations by Velz. Equation 18 stems from Deininger's direct solution to Fick's law of diffusion,

$$\frac{\partial m}{\partial t} = - D_L A \frac{\partial c}{\partial x} \qquad (19)$$

where ∂m is the mass of oxygen passing through a cross-sectional area A in time ∂t when the concentration gradient is $\partial c/\partial x$, where oxygen concentration is c at x, and D_L is a diffusion coefficient. Equations 13 and 14 modify Phelps' theory of quiescent diffusion to account for a waterbody that is mixing.

Equations 11 and 18 may be solved simultaneously for R and P at reach bottom. Velz resorts to a graphical method, but a direct search procedure on the computer resolves the two terms rapidly.

EQUIVALENT REAERATION COEFFICIENT

The Velz reaeration algorithm is more complex than a standard oxygen sag reaeration coefficient (K_2) approach, where the reaeration rate is equal to $K_2(1 - P)$. A K_2 equivalent, a constant applied to the DO deficit in a given reach that would indicate the amount of reaeration found by the Velz procedure, was determined by computer search for each reach in the lower Willamette. Mean equivalent K_2's, base 10, were: 0.18, Salem-Newberg, 0.05, Newberg Pool, and 0.02, tidal reach.

Values of equivalent K_2's are plotted on Figure C-26. Regressing equivalent K_2 on velocity, depth (Figures C-27(a) and (b)), and stream type, a rate model resulted as:

$$K_2 = \frac{1.437 \ U^{(0.160 - 0.190 \ N)}}{H^{(1.122 - 0.104 \ N)}} \qquad (20)$$

where K_2 = coefficient of reaeration, per day, base 10°c, 20°C,
              U = velocity, fps,
              N = 0, tidal regimes, below river km 43,
                   1, usual freshwater streams, above km 43, and
              H = depth, ft.

The significant interaction of stream type, depth and velocity upon equivalent K_2 explains why standard reaeration expressions not incorporating stream type may fail to adequately model Willamette DO under low flow conditions. It is possible that a judicious selection of a K_2 reaeration model might produce the generally good fit that the Velz method provides. DO simulations using alternative K_2 expressions taken from the literature, however, yielded no single reaeration formulation that adequately modeled existing data for the Salem to Portland Willamette main stem.

133
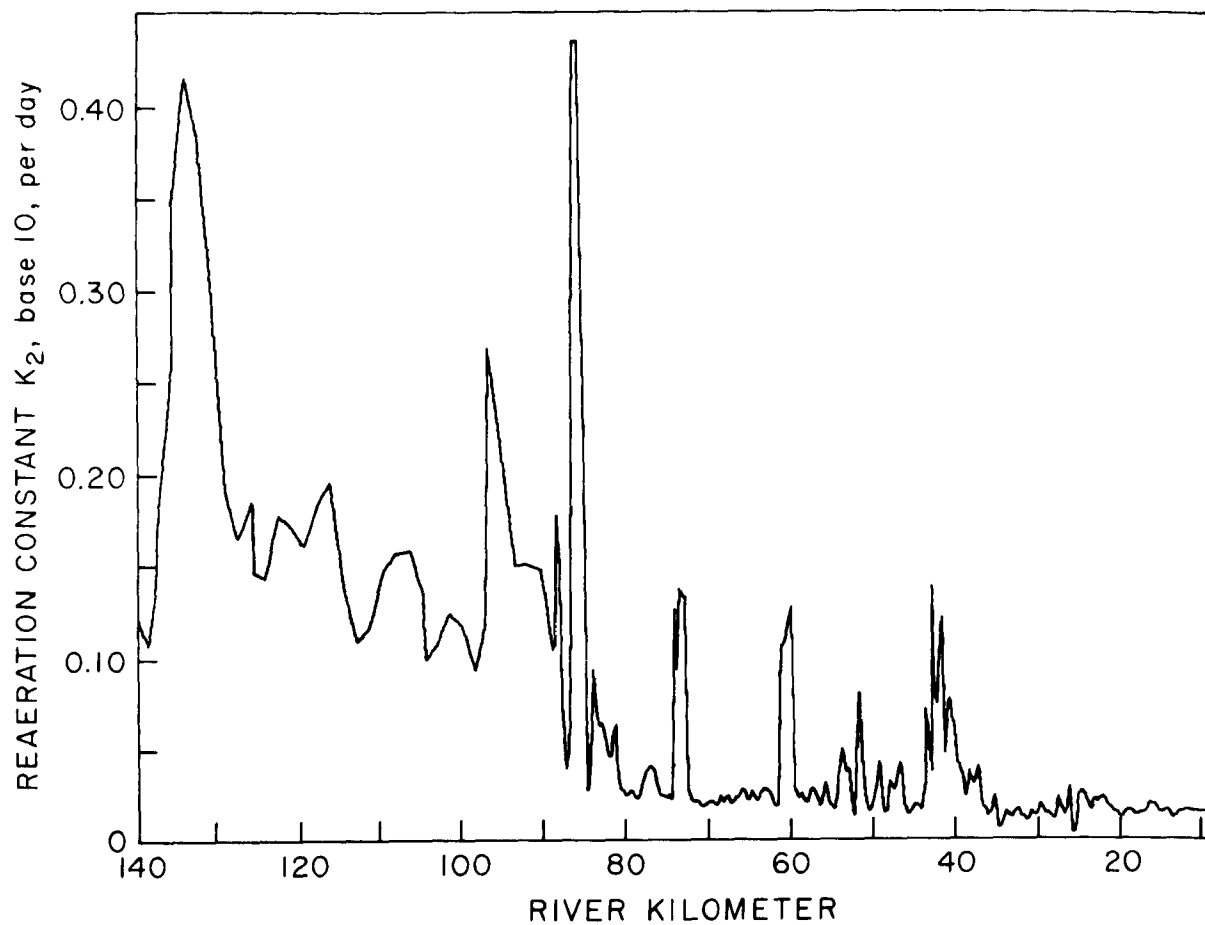
Figure C-26. Equivalent K_2 for Willamette low flow versus river kilometer.
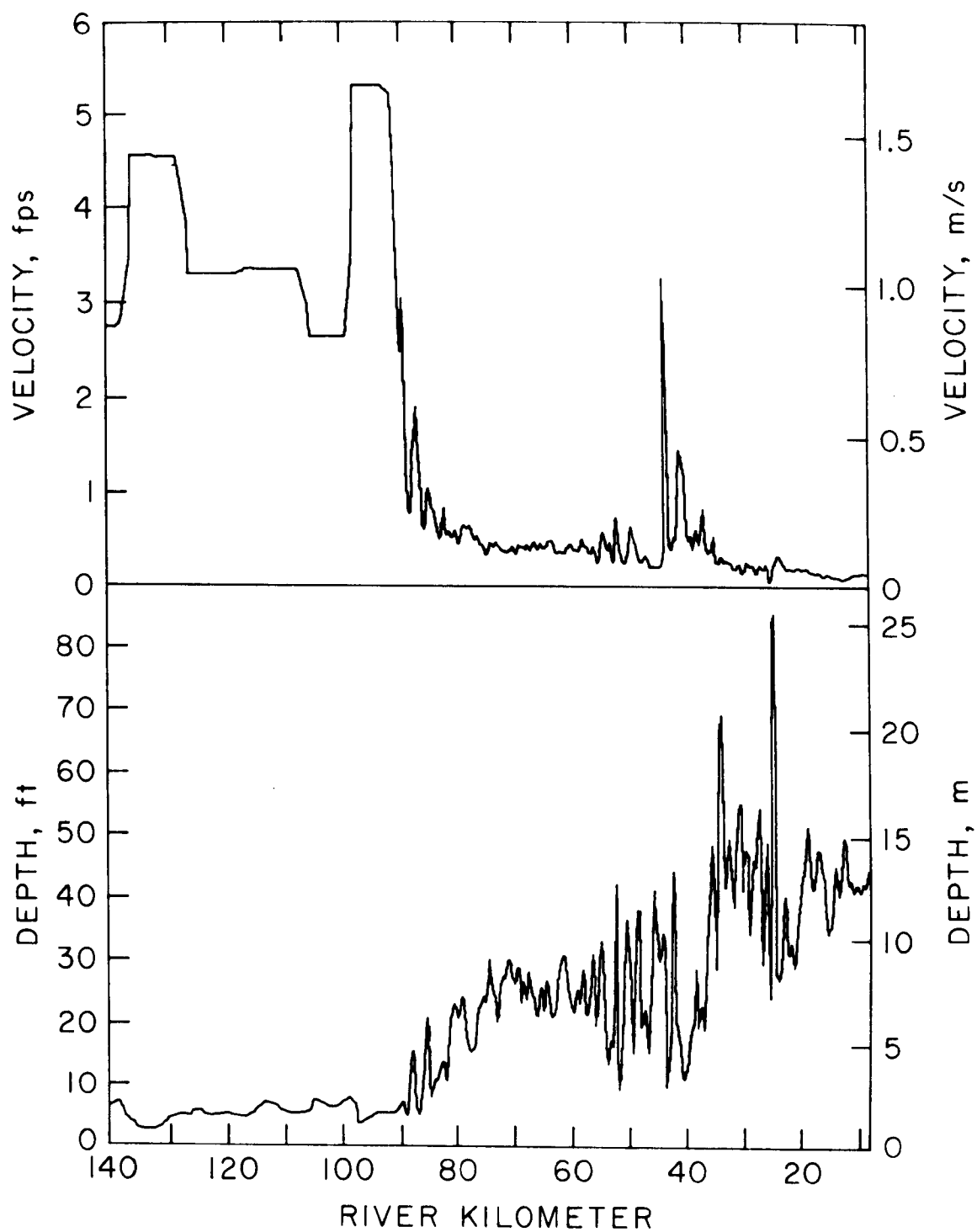
Figure C-27.   Stream (a) velocity and (b) depth for Willamette low
flow versus river kilometer (30).

135

APPENDIX D

MUNICIPAL AND INDUSTRIAL WATER SUPPLY

Willamette water is generally treated to remove natural sediment, a constituent not greatly affected by summer augmentation. Augmented flow would dilute coliform organisms, but it is unlikely that waterworks subsequently would reduce chlorination. Demands for municipal and industrial withdrawal have generally been satisfied without main stem augmentation. Municipalities and firms desiring a water less turbid than that of the Willamette can generally get it from tributaries. A change in low flow augmentation would not affect most municipal and industrial water supply.

IRRIGATION

Irrigation benefit is not significantly increased by water quality as long as quality remains aerobic. As long as present rights for agricultural abstraction are not impinged upon, present irrigation benefits will not decrease by having Willamette flow altered. There is current belief in the DEQ, however, that augmentation for water quality control may not have the legal right to usurp river flow divertable to irrigation expansion (10, 86). This belief stems from original reservoir authorizations for irrigation but not water quality benefits. Much of the augmented flow thus might properly belong to the farmers. If this is assumed, flow for quality augmentation might be valued at the benefits foregone by the irrigators.

In a typical year, main stem flow below the Santiam is augmented approximately 120 m^3/s for the 5-month drawdown season. Were this water to be employed for irrigation at \$5/af net return (a typical value for row crops in the Valley), a \$6.5 million gain would be realized by farmers (87). This corresponds to an approximate 10 percent increase in total production on all Basin irrigation lands. Such assumptions lead to a \$53 000 per m^3/s annual benefit for uniform drawdown for irrigation. This estimation is a high bound, for (1) the irrigation demand does not yet exist, (2) the value added would show decreasing returns to scale, (3) some irrigation return flow would occur, and (4) no allocation of streamflow would give irrigators complete rights to all augmented flow. This estimation of price, then, values water by imposing an assumed future policy of water management on a historical record of agricultural economics.

NAVIGATION

Flow maintenance for navigation is entirely complementary with flow maintenance for other benefits. As mentioned in Section IV, the

Willamette is decreasingly used for commercial transportation. Channel depth through Portland Harbor is more regulated by the tidal Columbia than by Willamette discharge. There is little economic evidence to suggest that total annual navigation use significantly depends upon summer low flow discharge. Navigation and channel maintenance are insensitive to DO quality.

HYDROELECTRIC POWER

A hydroelectric power cost or benefit attributable to low flow augmentation may be determined from augmentation's effect on through-turbine discharge, reservoir head, and the temporal pattern of generation. Figure D-28 traces (a) the mean head for powerhouses at multipurpose Willamette reservoirs; (b) total discharge from those reservoirs, partitioned into over-spillway and through-turbine flow; and (c) total net generation from those projects. Head is highest in the early summer. Water is spilled generally in the autumn. Generation varies with both head and turbine discharge. Low flow augmentation is largely responsible for the late summer drop in powerhouse head. As spill is not wasted in this period, through-turbine flow is not foregone. If the reservoirs were maintained at full capacity throughout the summer, thus providing some slight additional head for power, more water would be spilled from fall runoff, thus lost to power. Given that the reservoirs must be lowered for winter flood control, annual power production is not significantly altered by the late summer releases.

The timing of Willamette power generation reflects both hydroelectric power peaking strategy for regional needs and inter-regional management. The later summer drawdown and corresponding power produced is needed in California; power is repaid during the winter season when it is locally demanded. The cost of transhipment is outweighed by efficient utilization of power plants. An altered scheme for Willamette flow augmentation would not cause net power production to be substantially altered.

FLOOD PROTECTION

Like navigation and power, flood protection is a benefit independent of water quality. Deviation above the flood control rule curve (Figure 6(a)) represents loss of flood control capacity, thus potential penalty. Deviation below the rule indicates increased flood protection, a benefit if and only if there are flood damages yet reduced by such control.

An increased late summer flow may be operationally achieved by two rule curve modifications. A full pool may be maintained later into the summer and/or a minimum pool may be realized sooner in the autumn. In each instance, a steeper rate of drawdown increases late summer augmentation. The full pool held longer into the summer might decrease summer flood protection. Hydrologically, the Willamette is not apt to flood in this season. If it were to do so, normal rule allowance would compensate. A low pool earlier in the fall, another consequence of in-
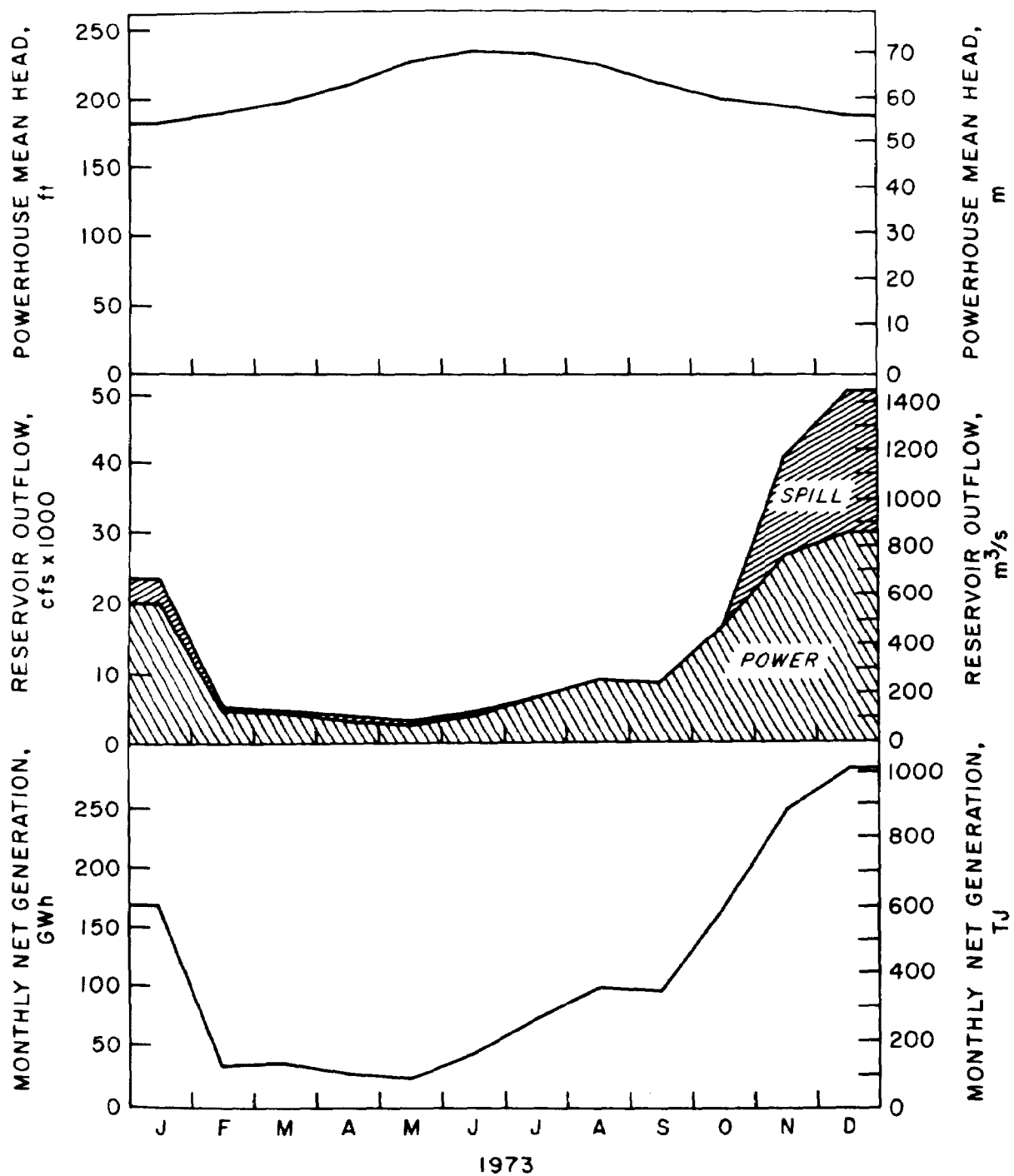
137

Figure D-28. Powerhouse head, reservoir outflow, and (c) generation, 1973 (88).

creased summer augmentation, may provide additional capacity for flood storage from early winter storms. This benefit, however, is not likely to be realized. Damaging floods commonly result from lack of total reservoir capacity, not inability to empty storage before the flood season.

RECREATION

Any policy of reservoir storage and release will have recreation impact. Recreation response to a program of main stem flow augmentation for quality control might include (1) increased downstream water-contact summer recreation, (2) increased downstream boating, (3) decreased water-edge reservoir recreation during the drawdown season, and (4) a decreased reservoir boating season. Whereas all four responses may occur in the case of the Willamette, any net annual impact of reservoir releases tends to cancel. Reservoir recreational visits by annual count do not seem to depend on drawdown. Recreation's insensitivity to reservoir drawdown is indicated by other studies (89). Undoubtedly, drawdown leads to changed patterns of recreation activities, but on the whole, no net gain or loss is foreseen to result from augmented main stem summer flow.

WASTE DISPOSAL

The ability of a river to satisfactorily carry away waste products is directly related to both discharge and receiving water quality. The greater the discharge, the faster the water's velocity, and the sooner the wastes will be flushed downstream. The greater the discharge, the more wastes will be diluted and the less problems of concentration they will create. The higher the water quality, the more assimilative capacity exists to biodegrade waste products. This study deals with estimating the waste disposal benefits of low flow augmentation. Such benefits therefore cannot be independently given, but rather are determined in Section IX.

FISH AND WILDLIFE

The return of fish to the Willamette has been shown to correspond to the river's cleanup. A loss of such a resource must carry with it a substantial regional economic penalty. In this study, however, it is not necessary to estimate the quantative nature of such a price. Any environmental strategy leaving the summer low flow with insufficient oxygen for fish passage is objectionable, thus not allowed. Natural obstructions and low flow hinder natural fish passage if limiting water quality levels are not violated. Credit for improvement upon passage, if allowed, should be given to the ladder at Willamette Falls, not the augmented level of flow itself.

APPENDIX E

METHOD

Methods for cost allocation are documented elsewhere (50). The method of allocation employed here is the separable costs-remaining benefit method, modified for equity. The equity modification is in compliance with Federal Inter-Agency River Basin Committee and Bureau of the Budget objectives for cost allocation procedures (51. The cost allocation procedure is as follows.

T = Multiple-purpose total project cost

S_x = Separable cost of purpose x

N = $T - \Sigma S$ = Total nonseparable costs

B_x = Benefits to purpose x

A_x = Alternative project cost for purpose x

J_x = $\min(A_x, B_x)$ = Justifiable cost of x

O_x = $\min(T-S_x, \Sigma J - J_x)$ = Justifiable costs combining all other purposes

E_x = $(O_x + J_x)/T$ = Correction for equity

R_x = $J_x - E_x S_x$ = Adjusted remaining benefit to x

N_x = $N \times R_x/\Sigma R$ = Adjusted nonseparable costs allocated to x

T_x = $S_x + N_x$ = Total cost allocated to x

Separable costs, S_x, are those expenses incurred solely in support of one project purpose, x. For a multipurpose project, total project cost, T, less separable costs yields the nonseparable remainder, N. Justifiable cost of a project purpose, J_x is the lesser of the benefit, B_x, afforded by purpose x, or the alternative cost, A_x, of obtaining that benefit from some other project. Justifiable cost combining all other project purposes, O_x, is the lesser of the cost of a project combining all purposes but purpose x, or the sum of all other justifiable single purpose costs.

Correction for equity, E_x, an allowance for fair distribution of cost savings to all project purposes, is obtained by adding justifiable single purpose cost to justifiable costs combining all other purposes and dividing by the total project cost. This allows each project purpose a savings proportional to the savings from inclusion of that purpose in the project. Without such correction, all project savings accrue entirely to nonseparable costs.

140

Adjusted remaining benefit, R_x, is the justifiable cost of a purpose less the separable cost of that purpose, corrected for equity. Adjusted nonseparable cost, N_x, is the portion of total nonseparable costs determined by the ratio of adjusted remaining benefit of a purpose to the total adjusted remaining benefits. Total cost allocated to a purpose, T_x, is the appropriate separable cost and adjusted nonseparable cost.

WILLAMETTE RESERVOIRS

The cost of Willamette multipurpose reservoirs allocated to water quality control may be simplified if two observations are made about the Willamette system. First, all projects are so extensively designed for flood control that no additional expenses are incurred for a program of summer release for whatever purpose. Secondly, augmentation benefits other than water quality have either lost much of their dollar significance (e.g. navigation) or may be thought of as not a co-equal benefit with water quality, but a benefit subsequently spunoff from water quality (e.g. fish and wildlife or recreation).

Flood control and hydroelectric power are project purposes, duly authorized and affording independent benefits. Municipal, industrial, and irrigation withdrawal benefits are assumed to be negligible if summer reservoir drawdown is left instream for flow augmentation. The remaining benefits (navigation, recreation, waste disposal, and fish and wildlife enhancement) are related to low flow maintenance, subsumed in the benefit of water quality control. Thus the multipurpose reservoirs provide three significant services: flood control (FC) hydroelectric power (HP), and water quality (WQ).

Table E-25 illustrates cost allocation for Basin reservoirs. Note that flood control benefits alone justify the entire project. Revenues from hydroelectricity just pay separable costs; hydroelectric power realizes no excess benefits with which to pay for nonseparable expenses. Were the value of power doubled while expenses held constant, costs would be allocated as shown in Table E-26. The cost allocated to water quality might drop several percent, a modification probably minor when compared to the imprecision in estimates for flood control returns upon which water quality charges also depend.

TABLE E-25. WILLAMETTE MULTIPURPOSE RESERVOIRS COST ALLOCATION

($ x 10^6/yr, 1973)[*]

Item		Hydropower	Flood Control	Water Quality	Total
Total Cost	T				45
Separable Cost	S	18	0	0	18
Nonseparable Cost	N				27
Alternative Cost	A	18	>98	Unknown	
Benefit	B	18	98	A_{WQ}	
Justifiable Cost	J	18	98	A_{WQ}	
Other Purposes	O	27	$\min\begin{cases} 45 \\ 18 + A_{WQ} \end{cases}$	45	
Equity	E	1.000	$(98 + O_{FC})/45$	$1 + A_{WQ}/45$	
Remaining Benefit	R	0	98	A_{WQ}	$98 + A_{WQ}$
Nonseparable Cost	N	0	$\dfrac{2678}{98 + A_{WQ}}$	$\dfrac{27\,A_{WQ}}{98 + A_{WQ}}$	
Total Cost	T	18			45

[*]Entries rounded to integer value

TABLE E-26. WILLAMETTE MULTIPURPOSE RESERVOIRS COST ALLOCATION
($ x 10^6/yr, 1973)*
Doubled 1973 Power Revenues

Item		Hydropower	Flood Control	Water Quality	Total
Total Cost	T				45
Separable Cost	S	18	0	0	18
Nonseparable Cost	N				27
Alternative Cost	A	36	> 98	Unknown	
Benefit	B	36	98	A_{WQ}	
Justifiable Cost	J	36	98	A_{WQ}	
Other Purposes	O	27	$\min \begin{cases} 45 \\ 36 + A_{WQ} \end{cases}$	45	
Equity	E	1.397	$(98 + 0_{FC})/45$	$1 + A_{WQ}/45$	
Remaining Benefit	R	11	98	A_{WQ}	$109 + A_{WQ}$
Nonseparable Cost	N	$\dfrac{295}{109 + A_{WQ}}$	$\dfrac{2678}{109 + A_{WQ}}$	$\dfrac{27\ A_{WQ}}{109 + A_{WQ}}$	
Total Cost	T	$18 + \dfrac{295}{109 + A_{WQ}}$			45

*Entries rounded to integer value

APPENDIX F

MODEL DEFINITION

Energy I/O modeling and economic I/O analysis are of similar nature. Because the economic model is I/O's most common employment, and because it is common to visualize dollar flow within an economy, an economic I/O example serves to both describe and illustrate the general nature of I/O analysis. An energy model is then formulated for example solution.

An Economic I/O Model

Assume a four sector economy of manufacturing (M), crude oil production (C), refined petroleum (R), and pollution control (P). Each sector in one time period, say a year, produces X_i units of output.

$$X_i = \sum_{j=1}^{n} A_{ij} X_j + Y_i \qquad (21)$$

where   n = sectors of the economy, 4 in this case,

X_j = total production by sector j,

X_{ij} = output from sector i used by sector j,

$A_{ij} = X_{ij}/X_j$, an empirical direct activity

coefficient, and

Y_i = output of i exported to final, non intrasector, demand

In the example case, X_R is the total production of, say, gasoline, X_{RP} represents the gasoline used by the pollution control sector, A_{RP} is the ratio of gasoline used in pollution control equipment production to pollution control equipment produced, and Y_R is the gasoline sold to households and government. Nonhomogenety within sectors precludes determination of the direct activity coefficients, A, as goods/good ratios. Dollar equivalents at producers prices are instead used. Thus X's and Y's are measured in dollars, A's as dimensionless fractions. Suppose dollar sales in a base year are:

Producer	Purchaser					
	M	C	K	P	Y	X
M	6	1	2	1	15	25
C	1	1	3	0	0	5
R	3	1	1	2	13	20
P	4	1	1	1	3	10

This table is known as the transaction table. The 3 in the third row represents $3 of refined petroleum sales to the manufacturing sector. The 6 in the first row represents $6 worth of manufactured goods sold within that same sector. The Y column is exogenous or final demand. The X column sums the row. Note that for each sector j to remain in business,

$$\sum_{i=1}^{n} X_{ij} < X_j$$

A table of direct activity coefficients is obtained by dividing the X_{ij} terms by the appropriate X_j. The resulting direct activity coefficient table is:

Purchaser	Purchaser			
	M	C	R	P
M	6/25	1/5	2/20	1/10
C	1/25	1/5	3/20	0
R	3/25	1/5	1/20	2/10
P	4/25	1/5	1/20	1/10

Thus it requires $6/25 of machinery, $1/25 of crude oil, $3/25 of gas, and $4/25 of pollution control to produce $1 worth of machinery. In algebraic form,

$$X_M = .24\ X_M + .2X_C + .10X_R + .10X_P + Y_M \qquad (22)$$

$$X_C = .04\ X_M + .2X_C + .15X_R + 0X_P + Y_C \qquad (23)$$

$$X_R = .12\ X_M + .2X_C + .05X_R + .20X_P + Y_R \qquad (24)$$

$$X_P = .16\ X_M + .2X_C = .05X_R + .10X_P + Y_P \qquad (25)$$

In matrix form, the economy is described:

$$\underline{X} = \underline{AX} + \underline{Y} \qquad (26)$$

Moving all X terms to the left, the matrix expression $(\underline{I-A})\ \underline{X} = \underline{Y}$ is obtained.

$$
\begin{bmatrix}
.76 & -.20 & -.10 & -.10 \\
-.04 & .80 & -.15 & 0 \\
-.12 & -.20 & .95 & -.20 \\
-.16 & -.20 & -.05 & .90
\end{bmatrix}
\begin{bmatrix}
X_M \\ X_C \\ X_R \\ X_P
\end{bmatrix}
=
\begin{bmatrix}
Y_M \\ Y_C \\ Y_R \\ Y_P
\end{bmatrix}
\qquad (27)
$$

To obtain X as a function of Y, total production as a function of final demand, the $(I\text{-}A)$ can be inverted and transposed.

$$
\underline{X} = \underline{(I - A)}^{-1}\,\underline{Y} \qquad (28)
$$

Doing this to the four-sector example, "direct plus indirect" coefficients result.

$$
\begin{bmatrix}
X_M \\ X_C \\ X_R \\ X_P
\end{bmatrix}
=
\begin{bmatrix}
1.422 & 0.467 & 0.234 & 0.210 \\
0.121 & 1.354 & 0.230 & 0.065 \\
0.267 & 0.430 & 1.164 & 0.288 \\
0.294 & 0.408 & 0.157 & 1.179
\end{bmatrix}
\begin{bmatrix}
Y_M \\ Y_C \\ Y_R \\ Y_P
\end{bmatrix}
\qquad (29)
$$

The values in the fourth row indicate the dollar increase in pollution control production necessary to allow a $1 increase in final demand from each column sector. Note that an additional $0.179 of interindustrial pollution control is needed to provide a dollar's worth of pollution control export in this example. Total outputs can now be determined necessary to satisfy both internal and external requirements of an arbitrary set of final demands. For the U.S. economy, $(I - A)^{-1}$, the direct plus indirect coefficients, have been determined for 1967 (92).

An Energy I/O Model

To this point, units have had monetary basis. The same model can likewise be applied to energy flow, say in joule units. The designator E can be used in similar fashion to the previous X.

$$
E_i = \sum_{k=1}^{n} E_{ik} + E_{iy} \qquad (30)
$$

where E_i = total energy output of sector i,

E_{ik} = energy output by sector i used by sector k, and

E_{iy} = energy output by sector i sold to final demand.

Recall that,

$$X_k = \sum_{j=1}^{n} (I-A)^{-1}_{kj} \, Y_j \qquad (31)$$

Multiplying E_{ik} by X_k/X_k,

$$E_{ik} = \frac{E_{ik}}{X_k} \sum_{j=1}^{n} (I-A)^{-1}_{kj} \, Y_j \qquad (32)$$

Then,

$$E_i = \sum_{k=1}^{n} \left[\frac{E_{ik}}{X_k} \sum_{j=1}^{n} (I-A)^{-1}_{kj} \, Y_j \right] + \left(\frac{E_{iy}}{Y_i}\right) Y_i. \qquad (33)$$

Define $R_{ik} = E_{ik}/X_k$, the energy component from sector i in a dollar of k production, and

S_i = the producer's price for energy sold to final demand

$= E_{iy}/Y_i$, i = energy sector

0, otherwise.

Combining terms in matrix form.

$$\underline{E} = [\underline{R}\,(I\text{-}A)^{-1} + \underline{S}]\,\underline{Y} \qquad (34)$$

As was $\underline{X}$ in dollars, $\underline{E}$ is the production of energy required both directly and indirectly to satisfy a final demand, $\underline{Y}$. Note that $\underline{R}$ is an empirical factor of production, $(\underline{I}\text{-}A)^{-1}$ has been previously determined, and $\underline{S}$ is another empirical value. The bracketed term $[\underline{R}(\underline{I}\text{-}A)^{-1} + S]$ may be designated $\underline{\varepsilon}$, the total energy matrix. Returning to the four-sector example, assume the following table of joule sales has been obtained from industrial records.

| | Purchaser | | | | | |
Producer	M	C	R	P	Y	X
M	0	0	0	0	0	0
C	2	1	37	0	0	40
R	5	1	2	1	16	25
P	0	0	0	0	0	0

Unlike the dollar requirement of viability, only the crude oil sector appears to produce a net energy. This sector, of course, achieves its 40 to 2 energy increase by drawing upon "free" input from the environment. Refined petroleum dollar and energy outputs are not necessarily proportional. Different energy pricing is allowed. The $\underline{R}$ matrix eliminates the non-energy rows, M and P.

$$\underline{R} = \begin{bmatrix} 2/25 & 1/5 & 37/20 & 0 \\ 5/25 & 1/5 & 2/20 & 1/10 \end{bmatrix} \tag{35}$$

Thus,

$$\underline{\varepsilon} = \begin{bmatrix} .08 & .2 & 1.85 & 0 \\ & & & \\ .2 & .2 & .1 & .1 \end{bmatrix} \begin{bmatrix} 1.422 & 0.467 & 0.234 & 0.210 \\ 0.121 & 1.354 & 0.230 & 0.065 \\ 0.267 & 0.430 & 1.164 & 0.288 \\ 0.294 & 0.408 & 0.157 & 1.179 \end{bmatrix}$$

$$+ \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 16/13 & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0.632 & 1.103 & 2.218 & 0.563 \\ 0.365 & 0.448 & 1.456 & 0.202 \end{bmatrix} \tag{36}$$

From this example matrix, it is seen that $1 final demand of pollution control requires 0.563 joules of production from the crude oil sector and 0.202 joules from the refined petroleum sector. The two values should not be summed, however, or a double counting of energy occurs.

THE PROBLEM OF DOUBLE COUNTING

When I/O is applied to dollar-only problems, columns of the $(\underline{I-A})^{-1}$ matrix are often summed to obtain the overall dollar flow response to unit of exogeneous demand. Summing the fourth column in the example $(\underline{I-A})^{-1}$ matrix, $1.742 of total production is generated by $1 final demand for pollution control. Such vertical summation is proper where one dollar,

148

passing through two hands, can be interpreted as having twice the economic impact as it would have had, had that dollar only passed through one hand.

Such addition is not proper for energy analysis. Unlike a dollar, a joule spent is a joule not to be spent again. In the example, two energy sectors provide joules for pollution control. But all the joules produced by the refining industry are transformed primary joules of crude oil. No energy is produced in refinement; energy quality is upgraded. From the viewpoint of resource management, the use of refined petroleum is of internal, not external, economic consequence. That which sustains the economy is primary input to the overall system, not the technology of energy circulation within. In this example, the primary requirement necessary for pollution control is 0.563 joules mined by the crude oil sector.

The problem of double counting can be illustrated by adding to the example model another sector, say one of refined petroleum transport, T. This activity can be thought of as before having been incorporated in the refining sector itself. The direct joule table adds row and column T. Let all 25 joules produced in R now go to T. These 25 are distributed by T as they were before by R. From an external viewpoint, the system behaves exactly as before. From the viewpoint of internal circulation there is a new step, more transfer, and an additional total energy co-efficient. Adding these coefficients for $1 of pollution control final demand, joule flow seems to be greater. The more numerous the economic partitions, the more interindustrial circulation results and the greater will be the total direct-plus-indirects. The net efficiency of the system, the cost of stock energy per unit of goods production, must only consider the primary coefficients relevant to external inputs. In this example, the primary energy requirement for $1 worth of P final demand is 0.563 joules.

The only example of direct energy demand by final demand is that of refined petroleum. Sixteen joules are exported for $13. In common energy usage, the term "direct" has a different meaning. Direct energy is the fuel value consumed in the final step of production, not the value of the fuel supplied to final, non-industrial, demand. The common usage of "direct" leads to 7/25, 2/5, 39/20, and 1/10 joules of crude and refined petroleum burned per dollar output of each sector. Values such as these correspond to energy estimates used in direct energy analysis of water pollution control strategy. These direct energy coefficients indicate the immediate, local demand for pollution control energy. The primary coefficients indicate the overall impact on the fossil reserves.

Table F-27 illustrates the two interpretations of direct energy and the primary requirement for the example economy. The first column is of interest only for sectors selling energy outside the industrial matrix. Table 9 in Section VIII lists the direct-for-production and primary energy I/0 coefficients for various sectors participating in pollution control activity. In effect, Table 9 is a real-value partitioning of the bottom illustrative line in Table F-27.

149

TABLE F-27.   INPUT/OUTPUT DIRECT AND PRIMARY ENERGY COEFFICIENTS
(J/dollar final demand)

Sector	Sales to final demand	Direct for production	Primary
M	0	0.280	0.632
C	0	0.400	1.103
R	1.231	1.950	2.218
P	0	0.100	0.563

This appendix describes the formulation of Table 10. See that table for abbreviation key.

Treatment Level A - All 1973 municipal plants are in operation, but down-graded to L if L, ASP, or ASPL in 1973, to P otherwise. All but two industrial dischargers release 7.5 times 1973 BOD and Kjeldahl N. The two exceptions reflect two major 1973 N discharges assumed to be uncon-trolled. Benthic and non-point demands are those of 1973.

Treatment Level B - As above, but industrial releases are three times those of 1973.

Treatment Level C - As above, but P plants are replaced by AS or TF, as indicated in 1973. Industrial releases are 1.5 times those of 1973.

Treatment Level D - August 1973 conditions.

Treatment Level E - Seven municipal plants are upgraded, three plants added, twenty-four plants abandoned, fourteen plants halt August dis-charge to river, and trunk sewers are added to regionalize areas with abandoned plants, all as recommended by DEQ. Industrial releases are 0.8 those of 1973. One sixth of the benthic demand is removed by regu-lation of Portland Harbor sewage overflows, ship discharges, dredging, gravel mining, and prop wash. Non-point sources are unchanged.

Treatment Level F - As above, but all plants are upgraded to ASEF, TFEF, or ASPL. ASP is allowed in place of ASPL only if downstream nitrification does not occur.

Treatment Level G - As above, but two industrial major N sources are re-duced to 0.1 of 1973 loadings.

Treatment Level H - All municipal and industrial loadings are removed. As economic and energy models employed for levels A-G are not suited for this option, a rough dollar and joule estimation is drawn from costs pro-jected of national leglislation directed toward elimination of point source pollution. Willamette costs are estimated to be one-third the national per capita figure, as the Willamette wastes are treatable by proven methods, (93).

TABLE H-28. WILLAMETTE BASIN WASTEWATER TREATMENT
SUMMARY OF DOLLAR AND ENERGY COSTS
Treatment Level A

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
Variable Costs	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Municipal Discharges Treatment Plants	41.853	3.649	2.306	5.955	410.578	120.166	140.695	2447.982	207.332	329.732
IOFLS	38.982	2.585	.321	2.906	559.800	16.727	30.722	1525.736	28.861	67.005
Industrial Pretreatment	.398	.044	.372	.416	3.904	13.146	13.303	23.279	33.214	31.145
Industrial Discharges	3.177	.373	.139	.512	31.166	4.912	6.471	185.823	11.290	20.531
Total	84.330	6.651	3.138	9.789	1005.449	154.952	191.190	4182.820	277.697	448.462
Fixed or Independent Costs										
Municipal Discharges Treatment Plants	11.652	1.016	.642	1.658	114.306	33.455	39.170	681.525	57.722	91.798
IOFLS	50.673	3.368	.418	3.786	729.194	21.742	40.012	1987.395	37.582	87.267
Industrial Pretreatment	.145	.016	.094	.110	1.422	3.322	3.379	8.481	7.635	7.974
Industrial Discharges	2.094	.246	.122	.368	23.542	4.311	5.339	122.478	9.989	16.033
Abandoned Facilities	5.838	.429	0	.429	57.192	0	2.860	340.997	0	17.050
Total	70.394	5.074	1.276	6.350	922.647	62.870	90.759	3140.876	112.848	220.122
Total	154.724	11.726	4.414	16.140	1929.096	217.822	281.949	7323.697	390.545	668.584

TABLE H-29. WILLAMETTE BASIN WASTEWATER TREATMENT
SUMMARY OF DOLLAR AND ENERGY COSTS
Treatment Level B

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
Variable Costs	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Municipal Discharges Treatment Plants	41.853	3.649	2.306	5.955	410.578	120.166	140.695	2447.982	207.332	329.732
IOFLS	38.982	2.585	.321	2.906	559.800	16.727	30.722	1525.736	29.861	67.005
Industrial Pretreatment	.398	.044	.372	.416	3.904	13.146	13.303	23.279	30.214	31.145
Industrial Discharges	23.417	2.751	1.027	3.779	229.721	36.294	47.780	1369.660	83.413	151.896
Total	104.578	9.029	4.026	13.055	1204.003	186.334	232.500	5366.658	349.820	579.777
Fixed or Independent Costs										
Municipal Discharges Treatment Plants	11.652	1.016	.642	1.658	114.306	33.455	39.170	681.525	57.722	91.798
IOFLS	58.673	3.368	.418	3.786	729.144	21.782	40.012	1987.395	37.582	87.267
Industrial Pretreatment	.145	.016	.094	.110	1.422	3.322	3.379	8.481	7.635	7.974
Industrial Discharges	2.094	.246	.122	.368	20.542	4.311	5.339	122.478	9.989	16.033
Abandoned Facilities	5.030	.429	0	.429	57.192	6	2.860	340.997	0	17.050
Total	78.394	5.074	1.276	6.350	922.647	62.870	90.759	3140.876	112.848	220.122
Total	174.964	14.103	5.302	19.405	2126.650	249.204	323.258	8507.534	462.668	799.899

TABLE H-30. WILLAMETTE BASIN WASTEWATER TREATMENT
SUMMARY OF DOLLAR AND ENERGY COSTS
Treatment Level C

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
Variable Costs	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Municipal Discharges Treatment Plants	65.366	5.699	2.935	8.634	641.240	152.943	185.005	3823.257	263.886	455.049
IOFLS	38.982	2.585	.321	2.906	559.800	16.727	30.722	1525.736	28.861	67.005
Industrial Pretreatment	.621	.068	.329	.397	6.092	11.627	11.971	36.322	26.721	28.174
Industrial Discharges	58.378	6.856	2.560	9.416	572.610	90.470	119.101	3414.061	207.923	378.626
Total	163.259	15.209	6.145	21.354	1779.742	271.767	346.699	8799.377	527.392	925.854
Fixed or Independent Costs										
Municipal Discharges Treatment Plants	11.652	1.016	.523	1.539	114.306	27.254	32.969	681.525	47.023	81.099
IOFLS	50.673	3.368	.415	3.786	729.184	21.782	40.012	1987.395	37.582	87.267
Industrial Pretreatment	.145	.016	.076	.092	1.422	2.686	2.743	8.481	6.173	6.512
Industrial Discharges	2.094	.246	.122	.368	20.542	4.311	5.339	122.478	9.909	16.033
Abandoned Facilities	5.830	.429	0	.429	57.192	0	2.860	340.997	0	17.050
Total	70.394	5.074	1.139	6.213	922.647	56.033	83.921	3140.876	100.687	207.961
Total	233.653	20.283	7.244	27.567	2702.389	327.800	430.620	11940.254	628.078	1136.815

TABLE H-31. WILLAMETTE BASIN WASTEWATER TREATMENT
SUMMARY OF DOLLAR AND ENERGY COSTS
Treatment Level D

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
Variable Costs	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Municipal Discharges Treatment Plants	67.194	5.858	3.190	9.038	659.173	165.711	198.670	3930.177	285.916	482.425
IOFLS	38.983	2.585	.321	2.906	559.814	16.728	30.723	1525.774	28.862	67.006
Industrial Pretreatment	.639	.070	.357	.428	6.270	12.631	12.882	37.384	29.030	30.525
Industrial Discharges	71.200	8.363	3.123	11.486	698.472	110.360	145.284	4164.488	253.634	461.859
Total	177.936	16.877	6.951	23.858	1923.729	305.430	387.559	9657.823	597.442	1041.915
Fixed or Independent Costs										
Municipal Discharges Treatment Plants	11.653	1.016	.551	1.567	114.312	28.735	34.451	681.562	49.588	83.658
IOFLS	53.674	3.368	.418	3.786	729.192	21.789	40.019	1987.415	37.594	87.280
Industrial Pretreatment	.145	.016	.081	.097	1.423	2.866	2.923	8.484	6.588	6.927
Industrial Discharges	2.894	.246	.123	.369	20.544	4.347	5.374	122.489	9.990	16.114
Abandoned Facilities	5.838	.429	0	.429	57.192	0	2.860	340.997	8	17.050
Total	70.395	5.075	1.174	6.248	922.663	57.738	85.627	3140.947	103.752	211.029
Total	248.331	21.952	8.155	30.107	2846.392	363.168	473.185	12798.770	701.194	1252.844

TABLE H-32. WILLAMETTE BASIN WASTEWATER TREATMENT
SUMMARY OF DOLLAR AND ENERGY COSTS
Treatment Level E

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
Variable Costs	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Municipal Discharges Treatment Plants	73.886	6.441	3.667	10.108	724.822	191.087	227.328	4321.592	329.700	545.780
IOFLS	58.202	3.868	.480	4.348	837.527	25.013	45.951	2282.682	43.157	100.224
Industrial Pretreatment	.703	.077	.413	.490	6.896	14.595	14.871	41.118	33.544	35.159
Industrial Discharges	79.426	9.329	3.483	12.812	779.169	123.089	162.046	4645.627	282.889	515.171
Total	212.217	19.716	8.043	27.759	2348.414	353.785	450.198	11291.020	689.290	1196.363
Fixed or Independent Costs										
Municipal Discharges Treatment Plants	12.487	1.089	.621	1.710	122.497	32.360	38.485	730.365	55.834	92.352
IOFLS	50.673	3.368	.418	3.786	729.184	21.792	40.012	1987.395	37.582	87.267
Industrial Pretreatment	.155	.017	.091	.108	1.521	3.216	3.277	9.066	7.391	7.754
Industrial Discharges	2.094	.246	.122	.368	20.542	4.311	5.339	122.478	9.909	16.033
Abandoned Facilities	25.994	1.913	0	1.913	255.001	0	12.750	1520.389	0	76.019
Total	91.403	6.632	1.252	7.884	1128.746	61.670	99.862	4369.693	110.716	279.425
Total	303.620	26.348	9.295	35.643	3477.160	415.455	550.061	15660.713	800.006	1475.788

TABLE H-33. WILLAMETTE BASIN WASTEWATER TREATMENT
SUMMARY OF DOLLAR AND ENERGY COSTS
Treatment Level F

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
Variable Costs	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Municipal Discharges Treatment Plants	82.844	7.222	4.521	11.743	812.700	235.589	276.224	4945.546	406.483	645.763
IOFLS	59.282	3.868	.480	4.348	837.527	25.013	45.951	2282.682	43.157	100.224
Industrial Pretreatment	.788	.087	.508	.595	7.730	17.953	18.262	46.090	41.260	43.103
Industrial Discharges	79.426	9.329	3.483	12.812	779.169	123.059	162.048	4645.627	282.889	515.171
Total	221.260	20.507	8.992	29.499	2437.126	401.644	502.485	11819.945	773.789	1307.258
Fixed or Independent Costs										
Municipal Discharges Treatment Plants	12.487	1.089	.681	1.770	122.497	35.487	41.612	730.365	61.229	97.747
IOFLS	50.673	3.368	.418	3.786	729.184	21.782	40.012	1987.395	37.582	87.267
Industrial Pretreatment	.155	.017	.100	.117	1.521	3.534	3.595	9.066	9.122	9.435
Industrial Discharges	2.094	.246	.122	.368	20.542	4.311	5.339	122.478	9.989	16.033
Abandoned Facilities	25.994	1.913	0	1.913	255.001	0	12.750	1520.389	0	76.019
Total	91.403	6.632	1.321	7.953	1129.746	65.114	103.307	4369.693	116.842	285.551
Total	312.663	27.139	10.313	37.452	3565.872	466.758	605.792	16189.638	890.631	1592.809

157

TABLE H-34. WILLAMETTE BASIN WASTEWATER TREATMENT
SUMMARY OF DOLLAR AND ENERGY COSTS
Treatment Level G

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
Variable Costs	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Municipal Discharges Treatment Plants	82.844	7.222	4.521	11.743	812.700	235.589	276.224	4945.546	406.493	649.760
IOFLS	54.202	3.868	.480	4.348	837.527	25.013	45.951	2282.662	43.157	160.224
Industrial Pretreatment	.788	.087	.505	.595	7.730	17.953	19.262	46.090	41.260	43.103
Industrial Discharges	83.861	9.850	3.837	13.687	822.676	135.600	176.733	4905.030	311.641	556.893
Total	225.695	21.028	9.346	30.374	2480.633	414.154	517.171	12079.348	802.541	1348.990
Fixed or Independent Costs										
Municipal Discharges Treatment Plants	12.487	1.089	.681	1.770	122.497	35.487	41.612	730.365	61.229	97.747
IOFLS	50.673	3.368	.418	3.786	729.184	21.782	40.012	1987.395	37.582	87.267
Industrial Pretreatment	.155	.017	.100	.117	1.521	3.534	3.595	9.066	5.122	8.455
Industrial Discharges	2.094	.246	.122	.368	20.542	4.311	5.339	122.478	9.909	16.033
Abandoned Facilities	25.994	1.913	0	1.913	255.001	0	12.750	1520.389	0	76.019
Total	91.403	6.632	1.321	7.953	1128.746	65.114	103.307	4369.693	116.842	285.551
Total	317.098	27.660	10.667	38.327	3609.379	479.269	620.477	16449.041	919.383	1634.531

158

The Input/Output estimation of primary energy cost may be particularly useful for future hydroelectric projects, capital intensive endeavors that are not infrequently challenged as costing more than they will ever produce. Traditionally, dollar benefit/cost analysis is used to resolve such an issue. A calculation of energy benefit/cost ratio might serve decision analysis in an energy-conscious society much as the dollar ratio is used when social goals are dollar production. The Willamette Basin Corps of Engineers reservoirs serve as an example case.

Five hydroelectric projects, nameplate generating capacity of 409.4 MW, net annual load factor of 44 percent, generated 1.56 TWh in 1973. Power-allocated construction costs in 1973 dollars of these projects was $420 million. Annual power production expenses were $1.267 million. The average annual cost for replacement of major components was $2.75 million.

The primary energy intensity for reservoir construction is 38 650 Btu per dollar. Therefore, construction primary energy cost for the five projects is:

$$\$420 \times 10^6 \times 38\ 650\ \text{Btu/\$} = 1.62 \times 10^{13}\ \text{Btu} \qquad (36)$$

If the expected project life is 100 years and the ratio of primary energy to unit job is fixed (energy and construction prices may vary, however), the average annual primary energy required for construction is 1.62×10^{11} Btu.

Assuming capital replacement has the same energy intensity as does capital construction, the average annual primary energy cost of major replacement is:

$$\$2.75 \times 10^6 \times 38\ 650\ \text{Btu/\$} = 1.06 \times 10^{11}\ \text{Btu} \qquad (37)$$

An energy intensity of 29 500 Btu per dollar may be applied to production expenses.

$$\$1.27 \times 10^6 \times 29\ 500\ \text{Btu/\$} = 0.37 \times 10^{11}\ \text{Btu} \qquad (38)$$

The total annual primary energy cost for the five hydropower plants is thus 3.05×10^{11} Btu.

The three primary energy sources of electrical power and their primary energy to generated electricity technical coefficients are:

Coal Fired Power Plants - 2.944 Btu/Btu
Oil Fired Power Plants - 3.072 Btu/Bru
Gas Fired Power Plants - 2.887 Btu/Btu

Using a typical conversion of 2.9 Btu of primary energy to produce 1 Btu of electricity, the 3.05×10^{11} Btu primary cost of the five hydro-plants, if diverted from the hydroprojects to direct thermal generation would have produced 1.05×10^{11} Btu of electrical energy.

The 1.56 billion kWWhyearly produced by the projects is equivalent to 53.24×10^{11} Btu. If the 1.05×10^{11} Btu of electrical production foregone is subtracted from this output, an average annual net output of 52.19×10^{11} Btu is derived from these projects.

An energy benefit/cost ratio may be calculated.

$$\frac{B}{C} = \frac{53.24 \times 10^{11} \text{ Btu}}{3.05 \times 10^{11} \text{ Btu}} = 17.46 \tag{39}$$

As the ratio is many-fold greater than 1.0, the energy-for-energy investment in the Willamette projects is productive.

APPENDIX J

Solar Input, IN

Incident solar energy at surface, $I = 17 \times 10^5$ Cal/m^2-yr
Basin area, $A = 29.676 \times 10^9$ m^2
Reflection from surface, $R = 0.36$ incident
$IN = I \times A (1 - R) = 3200 \times 10^{12}$Cal/yr

Primary Production, PP

Net primary production, $NP = 700$ g/m^2-yr
Bomb calometric energy content, $B = 5$ Cal/g
$PP = NP \times A \times B = 100 \times 10^{12}$ Cal/yr

Standing Crop, Biomass, SB

Standing crop density, $D = 1800$ g/m^2
$SB = D \times A \times B = 2600 \times 10^{12}$ Cal/yr

Standing Crop, Saw Timber, ST

Standing crop, saw timber, $S = 193$ Tg
$ST = S \times B = 960 \times 10^{12}$ Cal/yr

Economic Production, Non Saw Timber Biomass, PB

Crop harvest, $H = 1.87$ Tg/yr
$PB = H \times B = 9 \times 10^{12}$ Cal/yr

Economic Production, Saw Timber, PT

Log production, $L = 4.37$ Tg/yr
$PT = L \times B = 21 \times 10^{12}$ Cal/yr

Precipitation Potential Energy, P

Basin runoff, $BR = 1.089 \times 10^{12}$ ft^3/yr
Mean channel elevation above lower Willamette datum, $CE = 805$ ft
$P = BR \times CE \times 62.4$ lb.ft$^3 = 5.47 \times 10^{16}$ ft-lb/yr $= 17 \times 10^{12}$ Cal/yr

Hydropower Production, HP

$HP = 2221 \times 10^6$ kWh/yr $= 2 \times 10^{12}$ Cal/yr

Petroleum Import, PI

$$PI = 203 \times 10^{12} \text{ Btu/yr} = 51 \times 10^{12} \text{ Cal/yr}$$

Electrical Import, EI

Electrical consumption, $EC = 65.68 \times 10$ Btu/yr $= 16$ TCal/yr
$$EI = EC - HP = 14 \times 10^{12} \text{ Cal/yr}$$

Natural Gas Import, GI

$$GI = 78.28 \times 10^{12} \text{ Btu/yr} = 20 \times 10^{12} \text{ Cal/yr}$$

Energy Consumption, C

$$C = HP + EI + PI + GI = 87 \times 10^{12} \text{ Cal/yr}$$

Industrial Energy Consumption, IE

$$IE = 0.44 \ C = 38 \times 10^{12} \text{ Cal/yr}$$

Imports, M

Primary energy intensity (I/O),
Agricultural products, $AE = \ 9598$ Cal/$
Forest products $\quad$, $FE = 16402$ Cal/$
Manufactured goods $\quad$, $ME = 19156$ Cal/$
Services $\quad$, $SE = 11417$ Cal/$

Imports,
Agricultural products, $AI = \$176 \times 10^6$/yr
Forest products $\quad$, $FI = \$144 \times 10^6$/yr
Manufactured goods $\quad$, $MI = \$920 \times 10^6$/yr
Services $\quad$, $SI = \$950 \times 10^6$/yr

$$M = AE \times AI + FE \times FI + ME \times MI + SE \times SI = 34 \times 10^{12} \text{ Cal/yr}$$

Exports, X

Exports,
Agricultural products, $AX = \$ \ 184 \times 10^6$/yr
Forest products $\quad$, $FX = \$ \ 349 \times 10^6$/yr
Manufactured goods $\quad$, $MX = \$ \ 569 \times 10^6$/yr
Services $\quad$, $SX = \$1426 \times 10^6$/yr

$$X = AX \times AI + FX \times FI + MX \times MI + SX \times SI = 35 \times 10^{12}/\text{yr}$$

Gross Output, O

Gross output,
Agricultural products, $AG = \$ \ 766 \times 10^6$/yr
Forest products $\quad$, $FG = \$1204 \times 10^6$/yr

Manufactured goods   , MG = \$2190 x 10^6/yr
Services   , SG = \$6788 x 10^6/yr

$$O = AG \times AI + FG \times FI + MG \times MI + SG \times SI = 147 \times 10^{12} \text{ Cal/yr}$$

Industrial Consumption, IC

Consumption,
Agricultural products, AC = \$ 69 x 10^6/yr
Forest products   , FC = \$ 24 x 10^6/yr
Manufactured goods , MC = \$ 66 x 10^6/yr
Services   , SC = \$3503 x 10^6/yr

$$IC = AC \times AI + FC \times FI + MC \times MI + SC \times SI = 43 \times 10^{12} \text{ Cal/yr}$$

Net Production, N

$$N = O - IC = 104 \times 10^{12} \text{ Cal/yr}$$

Household Consumption, HC

$$HC = N - X + EC - IE = 118 \times 10^{12} \text{ Cal/yr}$$

1. REPORT NO. EPA-600/5-78-019	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Economic and Energy Analyses of Regional Water Pollution Control		5. REPORT DATE September 1978 issuing date
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Richard J. Heggen, Kenneth J. Williamson		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Water Resources Research Institute Oregon State University 115 Covell Hall Corvallis, OR 97331		10. PROGRAM ELEMENT NO. 1BA609
		11. CONTRACT/GRANT NO. 68-03-2397
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Research Laboratory - Athens, GA Office of Research and Development U. S. Environmental Protection Agency Athens, GA 30605		13. TYPE OF REPORT AND PERIOD COVERED Final, 4/76-4/78
		14. SPONSORING AGENCY CODE EPA/600/01

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Two strategic approaches to water quality control in Oregon's Willamette River are presently being utilized: point source treatment and flow augmentation from reservoirs. Input/Output analysis (I/O) provides an econometric methodology to study direct and indirect energy response to pollution control alternatives. An energy I/O national model is coupled with a comprehensive Willamette River dissolved oxygen model. Three approaches to environmental control for the Willamette are examined. One is that of current enforcement coupled with present levels of augmentation. Another consists of less augmentation and increased wastewater treatment. The third approach consists of increased flow augmentation for water quality control. Corresponding treatment is somewhat relaxed. Each alternative of environmental control is evaluated as if it had been practiced in a study year of low natural runoff. The relation of augmentation for water quality to other river uses is used to value flow in a benefits-foregone manner. Independently, reservoir costs are allocated to water quality. For alternatives of treatment and augmentation, river quality, dollar cost and energy impact response surfaces are developed. Indirect energy costs are roughly twice the direct energy use. Energy impact is substantially a reflection of treatment degree. Energy- and dollar-efficient management calls for the full role of augmentation in water quality control.

17.	KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Energy Cost effectiveness Stream pollution Multiple purpose reservoirs Sewage disposal Water resources Regional planning		Flow augmentation Willamette River (Oregon) Input/Output analysis Dissolved oxygen models	48H 48B 68D
18. DISTRIBUTION STATEMENT Release to Public		19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 176
		20. SECURITY CLASS *(This page)* Unclassified	22. PRICE