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EVALUATING WATER QUALITY IMPACTS OF SMALL STREAMS ON MAJOR URBAN RIVERS

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and
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Abstract

Application of the 1972 Federal Water Pollution Control Act Amendments to small urban streams presents complex managerial problems because of the dual role which these streams play in an urban water resources system. Each stream could provide a limited, yet valuable, set of intrinsic beneficial uses. Both collectively and individually, small streams influence the water quality of larger urban rivers. Before the intrinsic water quality demands of a small stream are evaluated, water quality goals to protect major river quality must be established.

Within any reach of a major river, differences in upstream and downstream water quality can be attributed to both:

(i) the tributary streams which enter the major river within the reach.

(ii) effluents (from both point and non-point sources) which enter the river directly.

This analysis determines what portion of major river degradation is due to the water quality conditions of the small streams. The methodology is illustrated with a case study of the region of Allegheny County, Pennsylvania (Pittsburgh SMSA), and concludes that for this region, little improvement in major river quality can be expected from upgrading the water quality of small streams.

Introduction

Recent water pollution control legislation at state and federal levels has provided strict controls to protect the integrity and quality of the nation's watercourses. The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) establish the national goal of zero discharge of pollutants

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by 1985. The act further establishes an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife, and for recreation in and on the water, to be achieved by July 1, 1983 [9]. To implement this act, the governor of each state was to designate areas within the state which had substantial water quality problems as a result of urban-industrial concentrations or other factors. Planning was then begun in an attempt to meet the national goals within the problem areas.

Both designation of and planning for problem areas have correctly been focused on major rivers within the urban areas. An urban area, however, consists typically of numerous small watersheds and storm drainage systems, draining into a small stream which eventually joins a large urban river. Nearly all the beneficial uses listed in the interim goal of PL 92-500 could be provided by a large urban river. Achieving these beneficial uses is often solely dependent on the water quality of the major river, which is partially determined by the water quality of small streams.

The small streams themselves, however, provide a valuable, yet often neglected resource. Although the potential for providing beneficial uses is severely limited irrespective of water quality, many are achievable. In particular, small streams can provide opportunities for local recreation and aesthetic enjoyment, uses particularly valued in a densely populated urban area. The role of small urban watersheds in water quality management is the particular focus of this study.

Dual Impact of Small Urban Streams

Although the economic and technological feasibility of compliance with the 1972 amendments will be debated at length, the amendments nevertheless provide the framework for efforts in water pollution control at present. When applying this legislation to small urban streams, complex management problems are encountered. The water quality conditions in small streams have a dual impact: not only do they affect the achievable beneficial uses of the individual watersheds, they also exert an influence on the water quality of major rivers.

Due to the dual impact of the small urban watersheds, water quality goals could be set either because of the water quality demands of the receiving rivers, or because of intrinsic demands on the small streams. At present, state and federal agencies are primarily interested in small watersheds as they affect implementation strategies for major rivers. Application of the legislation to protect small urban streams for their own sake usually rests with local regulatory authorities, often charged with responsibility for not one, but many such streams.

Because of budgetary limitations, the local authority usually cannot pursue a course of enforcement and implementation with equal vigor on all the streams under its charge. To do this would spread limited resources so thin that a wholly ineffective job would result. The local regulatory authority's first duty in the management of small urban watersheds is therefore to establish priorities. The method used to establish priorities must integrate the dual impacts to be expected through upgrading of the water quality of small urban streams. If the water quality in a small stream is such that it degrades the quality of the major river, thus limiting the achievable beneficial uses of the river, the small stream would be accorded management priority on that basis. Once that determination is reached, attention can be directed to protection of the intrinsic beneficial uses of the small stream. Several results are possible, for example:

(i) if the watershed has been assigned priority status based upon its impact of the major river, a still higher priority may be assigned to protect or preserve local beneficial uses of the watershed itself.

(ii) if the watershed has been found to exert a negligible effect on the major river, it may be accorded priority solely to protect or preserve local beneficial uses.

Thus, the first step in the management of urban watersheds is a determination of the impact which the water quality of the small streams exerts on the major rivers. Although information on the major rivers is usually readily available, data concerning small streams are typically very sparse, and thus the required analysis cannot normally be carried out using conventional methods. The objective of this study is to develop a methodology for performing the analysis under the data limitations often encountered by regulatory authorities. A case study of the region of Allegheny County, Pennsylvania (Pittsburgh SMSA) will be used to illustrate the methodology.

Description of the Study Area

Allegheny County, 730 square miles of densely populated and heavily industrialized area in southwestern Pennsylvania, includes 82 separate drainage areas. The 82 areas are listed in Table 1 under three categories:

(i) Watersheds of streams which are tributary to a major river (Allegheny, Ohio, Monongahela, or Youghiogheny) within the boundaries of Allegheny County.

(ii) Headwater areas of streams not tributary to a major river within Allegheny County.

(iii) Intervening areas directly abutting a major river, and not included in one of the well-defined watersheds.

The region (shown in Figure 1) is typical of urbanized areas throughout the United States with commercial and industrial activity concentrated along the banks of the major rivers. The analysis presented excludes the headwater areas since these have no influence on major river quality within the borders of Allegheny County. The headwater areas represent only about three percent of the total area of the study region.

TABLE 1
DRAINAGE AREAS IN THE STUDY REGION

Area	1970 Census Population	Total Area (square miles)	Area, Allegheny County (square miles)
Category I: Watershed Areas			
1. Beckets Run	611	3.53	3.10
2. Becks Run	21,965	2.87	2.87
3. Big Sewickley Creek	12,280	30.38	16.81
4. Bull Creek	18,651	49.75	23.66
5. Bunola Run	251	2.27	2.27
6. Campbells Run (tributary to Chartiers Creek)	4,046	5.81	5.81
7. Chartiers Creek (except Campbells Run, Millers Run, & Robinson Run	225,399	205.50	46.67
8. Crawford Run	1,043	1.97	1.97
9. Crooked Run	23,485	4.48	4.48
10. Days Run	3,749	4.65	4.65
11. Deer Creek	19,819	51.50	50.29
12. Douglass Run	3,929	10.20	9.23
13. Fallen Timber Run	5,700	9.75	9.75
14. Flaugherty Run	5,203	8.95	7.73
15. Girtys Run	44,543	14.22	14.22
16. Guyasuta Run	12,821	3.46	3.46
17. Homestead - West Run	38,351	5.69	5.69
18. Indian Creek	3,268	0.66	0.66
19. Jacks Run	19,559	3.04	3.04
20. Kelly Run	830	2.41	2.41
21. Kilbuck Run	755	5.17	5.17
22. Little Sewickley Creek	3,899	9.62	9.62
23. Lobbs Run	3,284	5.61	2.78
24. Long Run	32,474	17.36	10.22
25. Lowries Run	21,667	15.15	15.15
26. McCabe Run	9,432	1.66	1.66
27. Millers Run (tributary to Chartiers Creek)	8,783	24.48	11.35
28. Montour Run	9,399	36.67	36.67
29. Moon Run	3,758	5.28	5.28
30. Narrows Run	3,190	1.68	1.68
31. Nine Mile Run	57,011	6.68	6.68
32. Peters Creek	69,854	51.39	35.25
33. Pine Creek	67,050	66.88	66.88
34. Pine Run	9,904	5.90	5.90
35. Plum Creek	24,246	20.65	20.54
36. Pollock Run	4,152	8.10	0.63
37. Pucketa Creek	31,544	36.50	4.41
38. Quigley Creek	3,997	1.14	1.14
39. Riddle Run	1,241	1.88	1.88
40. Robinson Run (tributary to Chartiers Creek)	18,914	41.21	30.96
41. Sandy Creek	14,549	3.45	3.45
42. Saw Mill Run	160,161	19.34	19.34
43. Shades Run	4,809	1.44	1.44
44. Shouse Run	4,586	2.36	1.31

TABLE 1 (Continued)
DRAINAGE AREAS IN THE STUDY REGION

Area	1970 Census Population	Total Area (square miles)	Area, Allegheny County (square miles)
45. Spruce Run	12,662	2.38	2.38
46. Squaw Run	7,955	10.34	10.34
47. Streets Run	31,383	10.43	10.43
48. Sunfish Run	811	2.46	2.46
49. Tawney Run	11,208	4.83	4.83
50. Thompson Run	28,153	8.30	8.30
51. Thorn Run	2,930	2.03	2.03
52. Toms Run	1,966	2.24	2.24
53. Turtle Creek	187,907	148.00	48.95
54. Wildcat Run	3,630	3.99	3.99
55. Wylie Run	3,815	4.67	4.67
Sub-Total	1,326,582	1,012.36	620.78
Category II: Headwater Areas*			
56. Breakneck Creek (42.60)	424	4.12	4.12
57. Brush Creek (56.20)	2,901	8.77	8.77
58. Glade Run (40.80)	184	1.21	1.21
59. Potato Garden Run (10:31)	1.757	10.31	10.31
60. Raccoon Creek (164.17)	330	2.63	2.63
61. Raredon Run (9.52)	318	5.46	5.46
Sub-Total	5,914	32.50	32.50
Category III: Intervening Areas			
62. A - Oakmont	7,052	3.63	3.63
63. B - O'Hara	2,816	1.50	1.50
64. C - North Side	81,365	8.90	8.90
65. D - Emsworth	758	0.60	0.60
66. E - Glenfield	19	0.13	0.13
67. F - Leetsdale	1,799	1.17	1.17
68. G - Smithdale	39	0.51	0.51
69. H - McKeesport	16,909	1.53	1.53
70. I - Forward	130	0.49	0.49
71. J - Mt. Oliver	27,660	2.70	2.70
72. K - South Side	8,010	1.19	1.19
73. L - Stowe	14,496	3.86	3.86
74. M - Moon	1,171	0.57	0.57
75. N - Crescent	151	0.26	0.26
76. O - Braddock	27,522	3.22	3.22
77. P - Neville Island	1,985	1.62	1.62
78. Q - Ohio River Basin	7,675	5.09	5.09
79. R - Pittsburgh	246,672	20.33	20.33
80. S - Upper Allegheny River Basin	17,355	4.43	4.43
81. T - Upper Monongahela River Basin	24,217	6.59	6.59
82. U - Youghiogheny River Basin	12,347	8.40	8.40
Sub-Total	500,148	76.72	76.72
Grand Total	1,832,644	1,121.58	730.00

**Note:* Only the headwater area within Allegheny County was included in this study. The total area of the watershed (in square miles) is shown in parentheses.

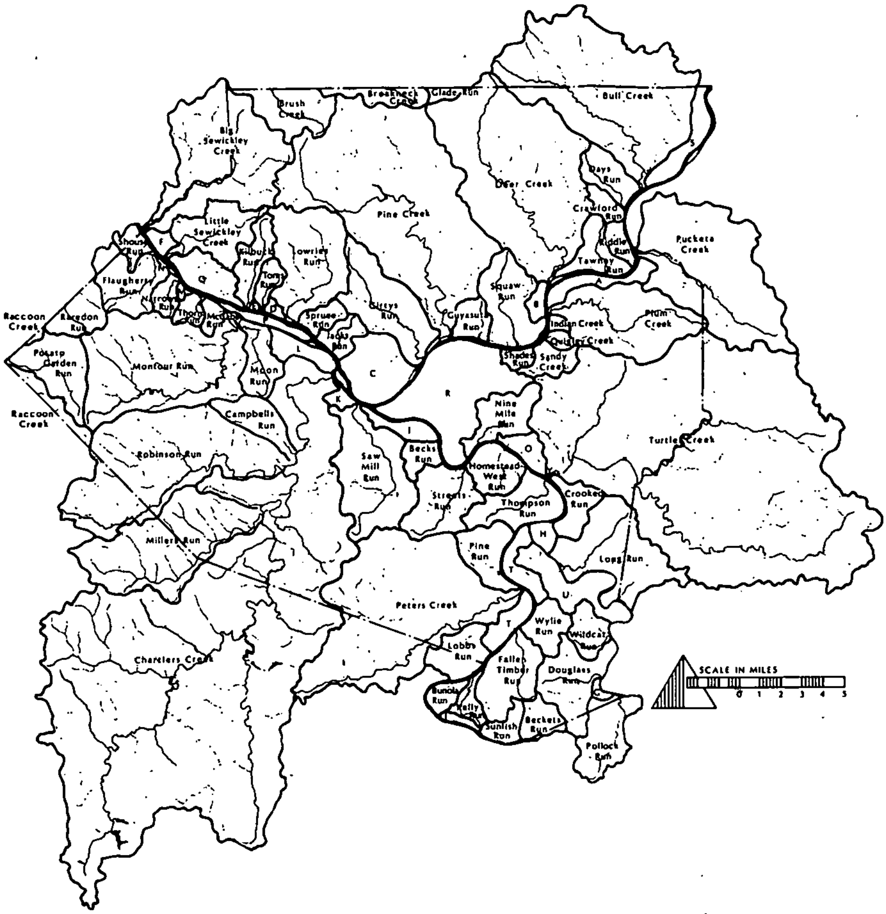


FIGURE 1: Allegheny County and Surrounding Watersheds

Methods of Analysis

The analysis of the impact on major river quality was approached through the following three tasks:

(i) comparison of the biodegradable organic loadings in small streams with those contributed by direct discharges to the major rivers.

(ii) analysis of the improvement in steady-state dissolved oxygen concentrations in the major rivers to be expected from reducing the biodegradable organic loading in the small streams.

(iii) analysis of the contribution of the small streams to the total dissolved solids load in the major rivers.

The first two tasks thus evaluate both the overall and localized impact on the major rivers due to the biodegradable organic load in the small streams. The impact which the streams exert on the inorganic (total dissolved solids) load in the major rivers is evaluated by the final task.

Comparison of Biodegradable Organic Loadings

An inventory of the major pollutant sources along the major rivers in Allegheny County has been compiled by the Environmental Protection Agency (EPA). This inventory includes industrial point sources and municipal sewage treatment plants.[6,11] In making the inventory, EPA has assumed best practicable treatment (BPT) for industrial discharges, and secondary treatment for all municipal sewage treatment plants with loads projected to 1980.

To evaluate the biochemical oxygen demand (BOD) load in the small streams, a knowledge of both streamflow and water quality characteristics is necessary.

Streamflow Predictions

Little streamflow data exist for the watersheds of the Allegheny County region. To estimate the total flow from the streams, records of eleven years (October, 1961 to September, 1972) of daily river flow were analyzed.[10] Major inflows are through the Allegheny, Monongahela, and Youghiogheny Rivers. Within the county (Figure 2) these three rivers join to form the Ohio River. Neglecting evaporative losses and infiltration, the streamflow in the Ohio leaving the Allegheny County region is the sum of the streamflows in the Allegheny, Monongahela and Youghiogheny Rivers, plus the runoff from the intervening drainage area (Figure 2).

Average monthly streamflow values were calculated for the following four gaging stations, shown in Figure 2:

(i) Allegheny River at Natrona
(ii) Monongahela River at Charleroi
(iii) Youghiogheny River at Sutersville
(iv) Ohio River at Sewickley

The monthly average runoff from the intervening drainage area was estimated as the monthly average streamflow at Sewickley, minus the sum of the monthly averate streamflows at Natrona, Charleroi, and Sutersville. The distribution of monthly average total runoff is shown in Table 2.

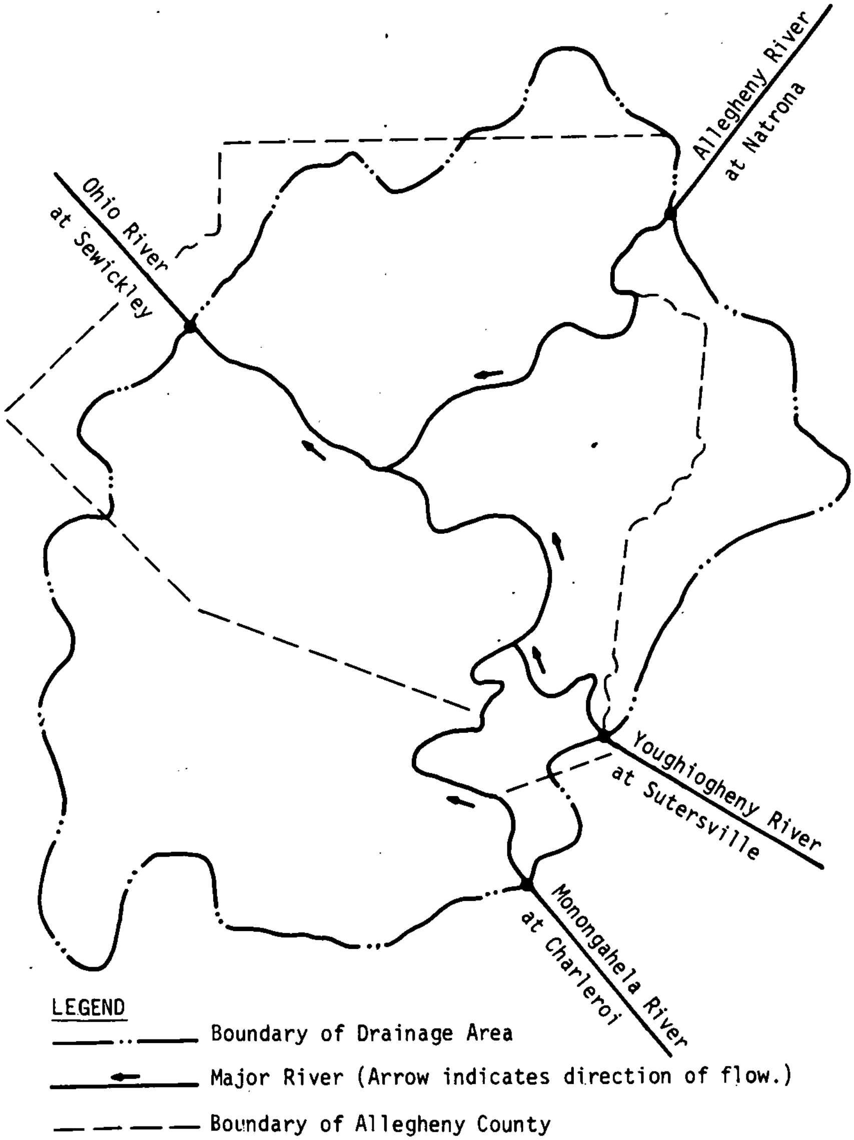


FIGURE 2: Allegheny County Flow System

Partitioning the Total Runoff Among Watersheds

Watershed area, precipitation, channel slope, soil type, land cover, and numerous other factors determine the volume of runoff contributed by a

TABLE 2
FREQUENCY DISTRIBUTION OF MONTHLY AVERAGE TOTAL RUNOFF FROM THE ALLEGHENY COUNTY REGION (CALCULATED BY OBSERVED DIFFERENCES)[14]

Percent of Time Given Total Runoff Was Exceeded	Total Runoff (cfs), 1961-1972 Monthly Average
10	2,400
20	1,600
30	1,200
40	940
50	740
60	580
70	450
80	340
90	235

Arithmetic Average = 960 cfs.
95% Confidence Limits = 160 - 3,400 cfs.

watershed. Thomas and Benson[7] conducted a study to relate streamflow to watershed characteristics statistically. The equations derived for watersheds in the eastern United States were applied to the drainage areas of Allegheny County to predict annual average streamflow values. The predictions for those individual areas which form the total intervening drainage area shown in Figure 2 were summed, and the resulting estimated total streamflow compared to the value obtained using observed differences. The observed annual average streamflow from the intervening drainage area is 960 cfs (Table 2), while the predicted value was 780 cfs.[6] The difference between these two values (18.8 percent) indicates that the equations predict average streamflow for the Allegheny County region quite well. The relative fraction of the predicted total streamflow contributed by each individual drainage area was used to partition a given value of total runoff among the separate drainage areas.

To determine the BOD loading contributed by the individual drainage areas, a total runoff value of 1,200 cfs was chosen. Since the worst water quality conditions usually occur during periods of summer low flow, analyses are typically performed assuming the occurrence of the seven-consecutive-day, ten-year low streamflow values. These values were used for streamflow in the four major rivers. However, to exaggerate the influence of the small streams, the 70 percentile value for total runoff was used. This choice has the effect of analyzing high streamflow volumes from the individual watersheds joining a low volumetric flow in the major rivers. Thus the analysis assumes:

(i) the worst water quality conditions in the major rivers; and,

(ii) very high influence from the small drainage areas throughout the region.

Both the overall load contributed by the individual drainage areas and the response to that load (change in dissolved oxygen concentrations in the major rivers) were analyzed under these conditions.

Concentrations of Dissolved Oxygen and Biochemical Oxygen Demand in Small Streams

Data for the small streams were compiled from records of the Allegheny County Health Department (ACHD), the Allegheny County Bureau of Tests (ACBT), and the Pennsylvania Department of Environmental Resources (Penn DER). Summer average concentrations of dissolved oxygen (DO) and five-day BOD (BOD_5) were computed. Unsampled streams were assigned stratified averages of the available data based on predicted overall water quality groupings from a previous study of watershed management.[3] Values for direct drainage areas and those streams not included in the previous study were assigned the overall averages for DO and BOD_5.[6] These values are shown in Table 3.

To apply the BOD data to the water quality model used, it was necessary to convert five-day BOD to ultimate BOD (BOD_{ult}). The ratio of BOD_{ult} to BOD_5 varies with the level of pollution. More polluted waters tend to have a lower BOD_{ult}/BOD_5 ratio. The ratio used by the Penn DER for municipal sewage treatment plant (STP) effluent is 1.45.[4] To determine an appropriate ratio for the county streams, BOD tests were performed on four streams of varying overall water quality (as shown in Table 3). The Thomas method[8] was used to calculate the reaction-rate constant, k, for each stream. From these analyses, the average reaction rate was calculated to be 0.14 (base e). The ratio BOD_{ult}/BOD_5 is thus 2.0, and this value was used to convert the BOD_5 concentrations to BOD_{ult}.

Overall Organic Loads

The total amount of BOD entering each of the four rivers within Allegheny County was computed. The overall totals for the county are shown in Figure 3 while those for each river are shown in Figure 4. Clearly demonstrated is the dominance of the Allegheny County Sanitary Authority (ALCOSAN) regional wastewater treatment facility. The 103,000 lb/day (BOD_{ult}) load represents about 42 percent of the total BOD load entering the rivers within the county. It is approximately equivalent to the total organic

TABLE 3
SUMMER AVERAGES OF DISSOLVED OXYGEN AND BOD_5 CONCENTRATIONS[3]

GROUP 1 (Worst Overall Water Quality)

	Dissolved Oxygen (mg/l)	BOD_5 (mg/l)
Becks Run	(7.6)	(4.1)
Bunola Run	6.0	(4.1)
Crawford Run	(7.6)	4.
Days Run	(7.6)	(4.1)
Fallen Timber Run	7.5	(4.1)
Girtys Run	(7.6)	(4.1)
Kellys Run	(7.6)	(4.1)
Millers Run	5.4	2.
Plum Creek	8.6	3.8, k*=0.14
Potato Garden Run	8.2	6.
Riddle Run	(7.6)	(4.1)
Saw Mill Run	8.5	8.
Spruce Run	(7.6)	1., k*=0.15
Streets Run	8.7	(4.1)
Thorn Run	(7.6)	(4.1)
Wildcat Run	(7.6)	(4.1)
Nine Mile Run	(7.6)	4.

GROUP 2

	Dissolved Oxygen (mg/l)	BOD_5 (mg/l)
Campbells Run	(9.0)	(3.5)
Crooked Run	(9.0)	2., k*=0.12
Homestead-West Run	(9.0)	(3.5)
McCabe Run	(9.0)	(3.5)
Montour Run	8.5	2.2
Moon Run	7.5	(3.5)
Narrows Run	(9.0)	(3.5)
Peters Creek	8.5	4.8
Pine Creek	10.7	1.8
Quigley Creek	(9.0)	1.
Robinson Run	8.9	(3.5)
Thompson Run	(9.0)	11.
Turtle Creek	9.0	3.5

GROUP 3

	Dissolved Oxygen (mg/l)	BOD_5 (mg/l)
Beckets Run	(9.2)	1.
Big Sewickley Creek	9.0	3.1
Bull Creek	11.4	1.
Chartiers Creek	8.3	3.0
Deek Creek	9.7	2.9
Douglass Run	(9.2)	1., k*=0.16
Flaugherty Run	10.5	(2.0)
Indian Creek	(9.2)	(2.0)
Jacks Run	(9.2)	(2.0)
Kilbuck Run	8.6	1.
Lobbs Run	(9.2)	(2.0)
Long Run	8.0	(2.0)
Lowries Run	8.2	4.
Pucketa Creek	(9.2)	1.4
Sandy Creek	(9.2)	(2.0)
Sunfish Run	(9.2)	(2.0)
Toms Run	(9.2)	2.
Wylie Run	(9.2)	(2.0)

GROUP 4 (Best Overall Water Quality)

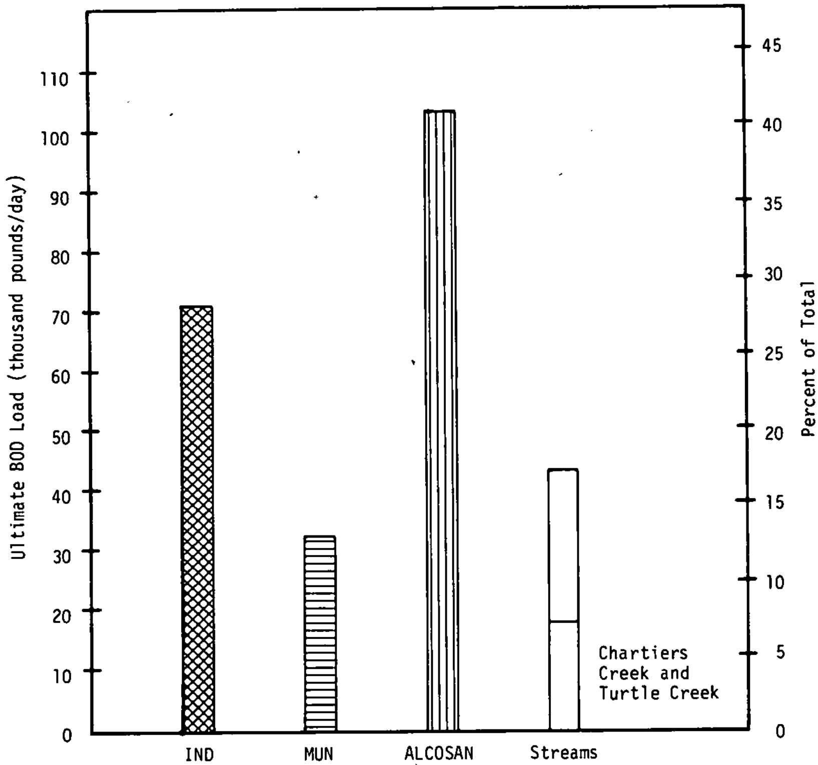
	Dissolved Oxygen (mg/l)	BOD_5 (mg/l)
Guyasuta Run	(9.9)	1.
Little Sewickley Creek	9.8	1.
Pine Run	(9.9)	(2.0)
Squaw Run	10.0	4.
Tawney Run	(9.9)	(2.0)

Overall Arithmetic Averages:
Dissolved Oxygen=8.7 mg/l
BOD_5=3.0 mg/l

Values in parentheses are the averages, in mg/l, of known data within the group.

*k=BOD reaction-rate constant (base e)

load from all other municipal wastewater treatment plants and industrial sources which enter the rivers directly. The total load contributed by the individual drainage areas in the region, about 43,000 lb/day (BOD_{ult}), represents only seventeen percent of the total. About seven percent of the total is attributable to Chartiers Creek and Turtle Creek, the largest two watersheds in the region. Deer Creek, Pine Creek, Peters Creek, and Saw Mill Run collectively account for about three percent of the total BOD load. Combined, all the remaining drainage areas contribute only about seven percent of the BOD load. Note that this analysis assumes high values of flow from



IND - Industrial point sources, best practical treatment, 1980
MUN - Municipal sewage treatment plants, secondary treatment, 1980
ALCOSAN - Secondary treatment, 1980
Streams - Total streamflow = 1,200 cfs

FIGURE 3: Total Organic Pollutant Load Entering Major Rivers in the Allegheny County Region

the streams and high levels of treatment at the industrial and municipal sources which enter the rivers directly; treatment levels not yet attained.

The distribution of BOD loads on each of the rivers is shown in Figure 4. On the Allegheny and Youghiogheny Rivers, the loads are fairly small, with municipal sewage treatment plants causing the biggest problem on the Allegheny. The small drainage areas collectively contribute a high proportion of the BOD load entering the Youghiogheny River within Allegheny County. On the Monongahela, industrial sources dominate, while on the Ohio, ALCOSAN contributes by far the greatest portion of the total load. The individual drainage areas contributing the greatest organic load drain into the Monongahela and Ohio Rivers.

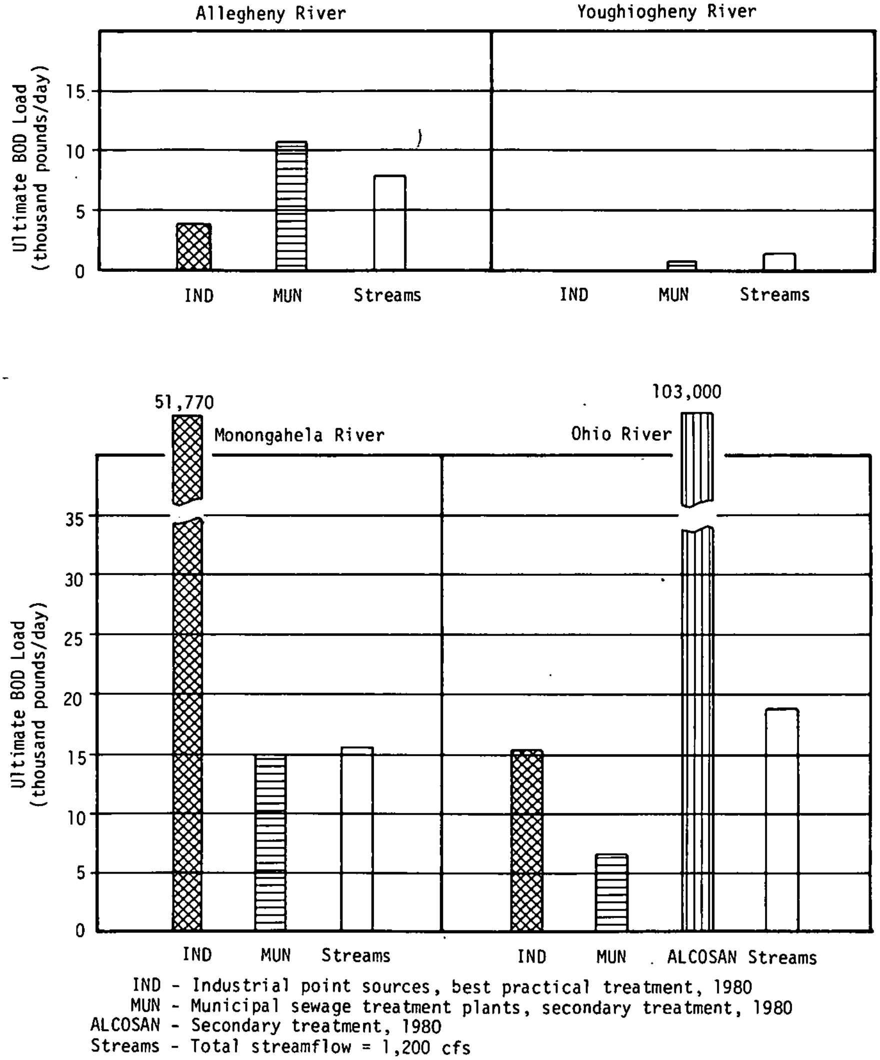


FIGURE 4: Organic Pollutant Load Entering Major Rivers: Allegheny, Youghiogheny, Monongahela, Ohio

The overall portion of organic loads due to the individual drainage areas is small. However, an additional analysis was performed to determine the expected improvement in dissolved oxygen concentrations in the major rivers resulting from reducing the organic load contributed by the individual drainage areas.

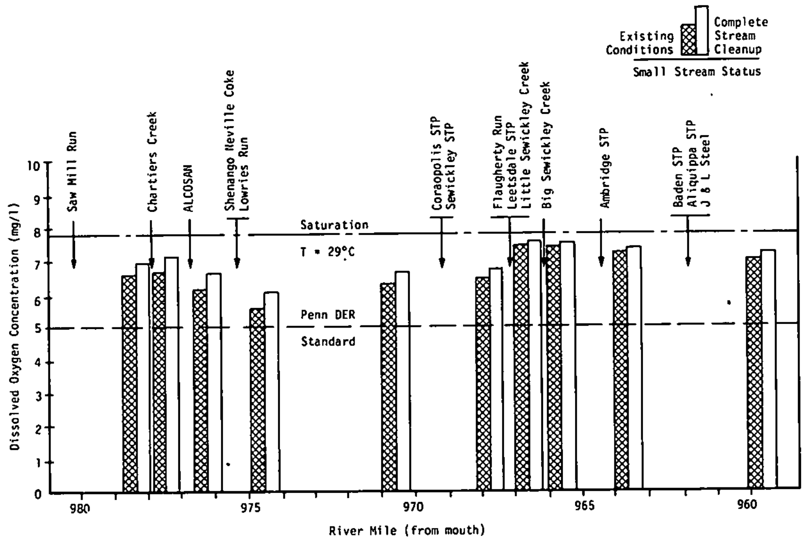


FIGURE 5: 1980 Projected Dissolved Oxygen Concentrations: Ohio River

Major River Response to Small Stream Improvement

The Environmental Protection Agency has developed a steady-state oxygen sag model for the Pittsburgh area.[11] The model requires BOD and DO loadings from point sources and applies first order reaction difference equations to predict BOD and DO concentrations along the river. The model accounts for varying velocities, deoxygenation rates, and reaeration rates along the rivers and over the locks and dams. All rate constants have been estimated by EPA, and the model has been verified by EPA with four separate surveys on the Ohio River and three on the Monongahela.[6]

To assess the maximum impact which the streams could have on the rivers under steady-state conditions, the model was used under two conditions of loading:

(i) normal pollution load contributed by individual drainage areas.

(ii) assuming BOD=0 mg/l and DO=10 mg/l (or higher, in the few cases that the normal summer average exceeds 10 mg/l) for all drainage areas.

In both cases, seven-consecutive-day, ten-year low streamflow was assumed in the Allegheny, Monongahela, and Youghiogheny Rivers. This low streamflow received a high value of runoff (1,200 cfs, the streamflow exceeded only 30 percent of the time), partitioned among the individual drainage areas.

The difference in the resulting DO concentrations along the major rivers

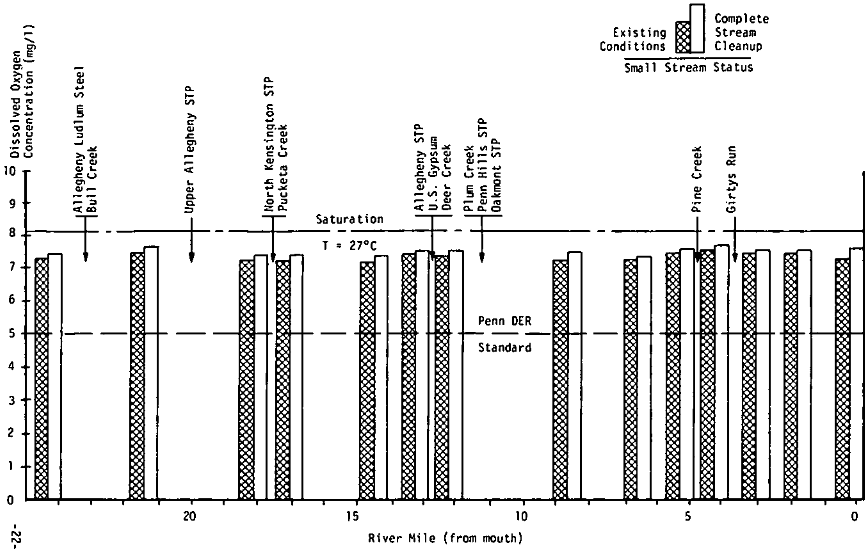


FIGURE 6: 1980 Projected Dissolved Oxygen Concentrations: Allegheny River

between the above two conditions of loading gives a good indication of the maximum impact of the tributaries, and thus the maximum major river response to an absolute cleanup of the small streams. (Note that realistically, some background BOD in the range of 2 mg/l BOD_{ult} would be inevitable). The DO profiles which result are plotted in Figures 5 through 9, comparing the response to the normal BOD load with the zero BOD load case. The locations of the major point sources and tributaries are shown on the graphs, as are the dissolved oxygen saturation level for the given temperature and the Penn DER water quality standard for the rivers, (DO=5 mg/l, minimum daily average).

The results demonstrate that only small, and in general, negligible, differences in predicted DO concentrations exist. At no point do DO concentrations fall below the 5 mg/l Penn DER standard in the unimproved case. The greatest single difference in DO concentrations between the improved and unimproved cases is 0.5 mg/l, occurring along the Monongahela downstream of Turtle Creek (Figure 8, River Mile 8.5).

Examination of the DO profile for the Ohio River (Figure 5) demonstrates the impact of ALCOSAN. There is a noticeable oxygen sag from the effluent of the ALCOSAN facility, between River Miles 967 - 977 (Figure 5). Downstream, water quality is further deteriorated by the Shenango Coke Plant on Neville Island (River Mile 975.5, Figure 5). (Note that only the main channel around Neville Island is shown, since it has a lower DO concentration than the back channel). The major stream impact occurs at the source of the

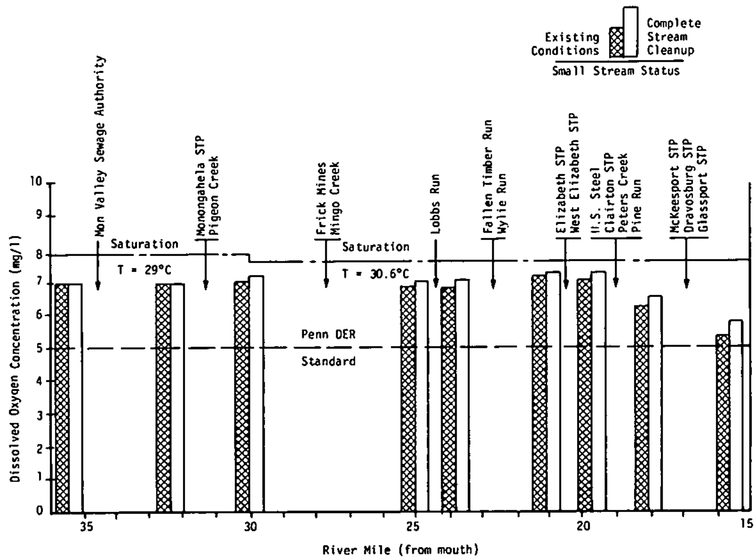


FIGURE 7: 1980 Projected Dissolved Oxygen Concentrations: Monongahela River (Mile Points 36 - 15)

Ohio River, near the confluences with Saw Mill Run and Chartiers Creek (River Miles 978 - 980, Figure 5). These two streams, along with Lowries Run may require more care, since they enter near the "hot spot" of the river, ALCOSAN. Figure 5 does show, however, that under both conditions of loading, significant water quality impact on the Ohio River within Allegheny County is projected to occur in the vicinity of the ALCOSAN sewage treatment facility.

The results of the analysis of the Allegheny River are shown in Figure 6. DO levels remain fairly constant with insignificant differences between the two cases of organic loadings.

The problems found along the Monongahela are probably the most severe. The DO profile is plotted in Figures 7 and 8. The first major problem occurs at River Mile 18 (Figure 7) where the Clairton Coke Works of U.S. Steel, the Clairton municipal sewage treatment plant, Pine Run, and Peters Creek all enter the river. There is a drop in the total DO concentration, and an increase in the difference between the river responses to the two conditions of loading. Three municipal sewage treatment plants in the next reach further affect the water quality and the DO level drops near 5 mg/l standard, at River Mile 15. The Monongahela recovers when it is met by the cleaner Youghiogheny. The next problem occurs as Turtle Creek and Thompson Run enter the river in the same areas as the Edgar Thompson Works of U.S. Steel and the Duquesne municipal sewage treatment plant (River Miles 11 - 13, Figure 8). The river begins to recover, but is further

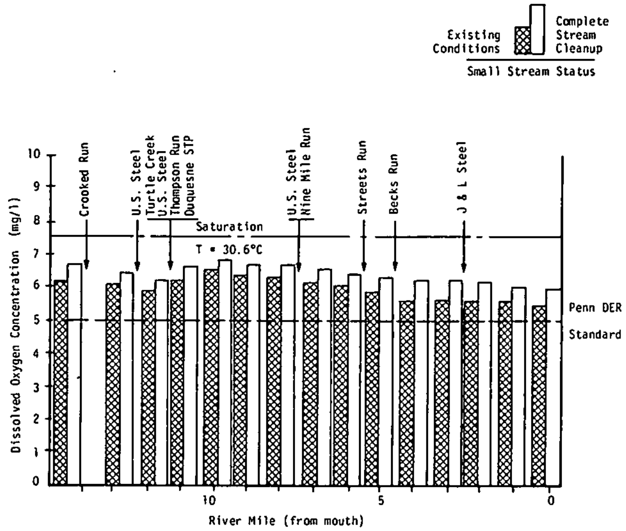


FIGURE 8: 1980 Projected Dissolved Oxygen Concentrations: Monongahela River (Mile Points 15 - 0)

degraded by U.S. Steel at Homestead and J & L Steel, and an extended sag is noticeable from River Mile 10 to the mouth. Here again, the differences due to stream improvement are predicted to be small, even in this extreme case. There may be some concern for the areas around Peters Creek and Pine Run (River Mile 19, Figure 7) and Turtle Creek (River Mile 11, Figure 8), because of their coincidence with other large point sources. The analysis does show, however, that the tributaries have a small impact on water quality in the Monongahela River.

The Youghiogheny River analysis, shown in Figure 9, indicates there is no DO problem from organic pollutant loadings along that portion of the river in Allegheny County, either from industrial sources, municipal sources, or the tributaries. Figure 4 indicates that the greatest proportion of the organic load entering the Youghiogheny River is from the combined effects of the small streams. This analysis has shown that eliminating that load completely produces a negligible improvement in the dissolved oxygen content of the Youghiogheny River.

Inorganic Pollutant Load

Thus far, the analysis has shown that the overall organic load contributed to the rivers by the small drainage areas is negligible. In addition, the improvement in the rivers' dissolved oxygen concentrations resulting from an absolute cleanup of the small streams is barely noticeable. Analysis was next directed toward evaluating the impact on major river quality resulting from the inorganic load contributed by the small drainage areas.

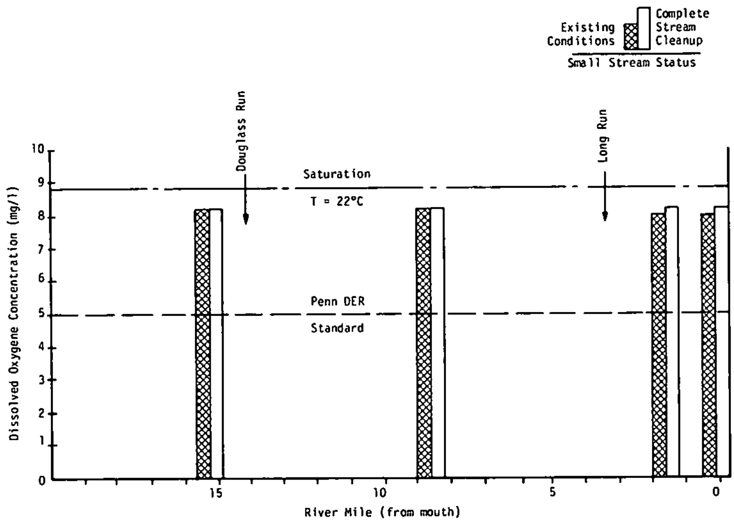


FIGURE 9: 1980 Projected Dissolved Oxygen Concentrations: Youghiogheny River

Once streamflows have been calculated, they may be studied in combination with pollutant concentration data to determine pollutant load. This was done for total dissolved solids (TDS), which is a good measure of the inorganic pollution problems of a body of water. This approach is conservative; concentrations vary only with the mass of dissolved solids and the volume of streamflow. Findings on the impact of the streams on the TDS problem in the rivers may be applied to other non-reactive pollutants.

To measure the potential overall TDS impact of the small streams, various runoff totals were assumed to enter the county rivers at various average TDS concentrations. The resulting portion of the TDS concentration in the Ohio River due to the TDS load contributed by the small streams was then calculated. Two cases were considered:

(i) median flow in the Ohio River (flow at Sewickley=20,000 cfs),

(ii) low flow in the Ohio River (flow at Sewickley=6,400 cfs, exceeded about 85% of the time[1]).

The resulting effects are plotted in Figures 10 and 11. Noted on the graphs are the Penn DER TDS standard of 500 mg/l (monthly average) and the calculated weighted average of the county streams: 770 mg/l. The average was calculated by weighting available TDS data[2] with predicted flows for those watersheds draining into the rivers upstream from Sewickley. The graphs show that the impact of the streams is minimal.

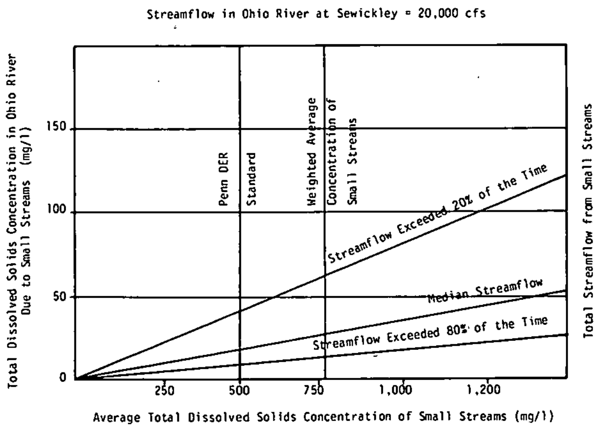


FIGURE 10: Total Dissolved Solids Concentration in Ohio River (Median Flow) Due to Total Dissolved Solids from Allegheny County Streamflow

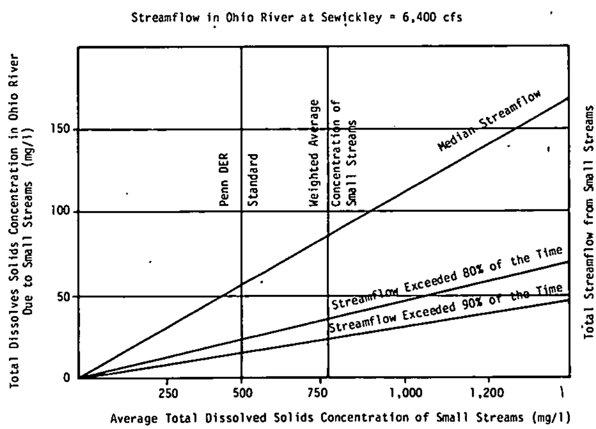


FIGURE 11: Total Dissolved Solids Concentration in Ohio River (Low Flow) Due to Total Dissolved Solids from Allegheny County Streamflow

Figure 10 assumes the following:

(i) median streamflow in the Ohio River at Sewickley (20,000 cfs),

(ii) weighted average TDS concentration (770 mg/l) in the county streams.

Under these assumptions, varying the value of total runoff from the individual drainage areas from the 20 percentile to the 80 percentile (340 - 1,600 cfs, monthly average) in no case contributes more than 60 mg/l to the total concentrations of TDS in the Ohio River at Sewickley. Assuming median streamflow conditions in both the individual drainage areas (740 cfs, monthly average) and the Ohio River at Sewickley, the small streams contribute about 25 mg/l to the TDS concentration measured at Sewickley.

Even assuming the worst conditions:

(i) low streamflow in the Ohio River at Sewickley (6,400 cfs),

(ii) weighted average TDS concentration (770 mg/l) in the county streams,

Figure 11 indicates that the effect is small. Assuming the median streamflow value (740 cfs, monthly average) for the small streams, the contribution to the total concentration of TDS in the Ohio River at Sewickley is about 80 mg/l. Under the above assumptions, note that reducing the weighted average TDS concentration (770 mg/l) in the small streams to the Penn DER standard (500 mg/l) reduces the average TDS concentration in the Ohio River at Sewickley by about 30 mg/l. These values can be compared to the average TDS concentration in the Ohio River at Sewickley, 254 mg/l.[5] This value (254 mg/l) is about one-half the Penn DER standard (500 mg/l). The above analysis has shown that even under assumptions which tend to exaggerate the impact of the individual drainage areas, a TDS problem in the major river is unlikely to be caused by the TDS concentrations in the small streams. Further, reducing TDS concentrations in the small streams will likely have a minor impact on concentrations in the major rivers, which are already well below the Penn DER standard.

Summary and Conclusions

An in-depth study of the effect of low water quality in the small streams on the quality of water in major rivers in Allegheny County (1974) has demonstrated that the small stream impact is minimal. The flow from the streams is small compared to the flow of the rivers, and the pollution load delivered is small compared to the load from industrial and municipal point sources along the rivers. This conclusion assumes the following:

(i) present pollution levels in the small streams.

(ii) best practicable treatment applied to industrial sources.

(iii) secondary treatment at all municipal wastewater treatment facilities, with loads projected to 1980.

The study included both inorganic and organic pollutant problems. Total flow frequencies from the tributaries were estimated by analyzing river data, and a prodecure determined for partitioning this flow among the small streams and drainage areas. Total dissolved solids, BOD, and DO data were gathered and compiled for the streams. An analysis showed that the overall stream impact on TDS concentrations in the Ohio River is minimal. The

BOD and DO data were used to include the streams in an EPA inventory of point sources along the major rivers, and a water quality model was utilized to predict the response of the rivers to these point sources. It was demonstrated that the overall loads from the streams are small relative to other sources of organic pollution, and that even with extreme assumptions, little response in the quality of the major rivers can be expected from improvements in the water quality of small streams.

Note that while the major constituents of the inorganic and organic pollution problem, TDS, BOD, and DO concentrations, have been studied, there are other sources of river deterioration which have not been investigated. Of particular importance are problems with coliform bacteria and mine acid. The data and techniques necessary to analyze the county stream impact on these problems are not presently available, and this may be an important area for future research.

The methodology for assessing the impact of small streams on major rivers has been illustrated using the case study of Allegheny County, Pennsylvania. This analysis has shown that for this particular area, local priorities can be set for individual drainage areas, independent of their negligible effect on water quality in the major rivers. The intrinsic demands on each stream can determine local management priorities throughout the Allegheny County region, and the benefits of cleaning up the small streams must be measured within the individual watersheds.

Acknowledgements

The work reported in this paper was performed while both authors were students at Carnegie-Mellon University, Pittsburgh, PA. Mitchell Small was employed by the Allegheny County Health Department, Division of Water Quality and Solid Waste Control, under the internship program of the Program in Engineering and Public Affairs at Carnegie-Mellon University. The contributions and cooperation of E. Dale Wismer of the Basin Planning Section, Water Programs Branch, U.S. Environmental Protection Agency, Region III, are gratefully acknowledged, as are those of Wilder D. Bancroft of the Allegheny County Health Department and Francis Clay McMichael and Robert W. Dunlap of Carnegie-Mellon University.

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SECOND INSTALLMENT

HYDRAULICS IN THE UNITED STATES 1776 - 1976

BY

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Institute of Hydraulic Research
The University of Iowa
Iowa City

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CHAPTER III

HYDRAULICIANS OF THE LATE 19TH CENTURY

An event that predated both the Civil War and the passage of the Morrill Act was the discovery of gold in California, but in its way it had an effect of comparable magnitude upon the course of our country. Our particular interest in it so far as the story of American hydraulics is concerned lies in the part that water played in obtaining and processing the ore. Not only in the placer form of mining but in the separation of the metal from the gravel and crushed rock, vast quantities of water were used. Early pipes, hoses, and nozzles were crudely improvised, and the common measure of discharge, the miner's inch (after the French *pouce d'eau*), was surely of a kind. But methods and facilities gradually improved in refinement and capacity. By 1869 a 30-inch riveted-steel inverted siphon operated safely under a 600-foot head, and only three years later a 12-inch pipe 7 miles long withstood a maximum head of 1700 feet. Water also provided the major source of power. At the Comstock Lode an ejector pump utilized a 2000-foot head to lift water from a mine 400 feet deep. Whereas the heads used for turbines in the East were relatively small and the rates of flow large, just the contrary was the case in the more mountainous West. Thus, while the turbines that were developed in the East were usually of the so-called reaction type, the Westerners instinctively turned to the impulse type, a primitive form of which was the hurdy-gurdy wheel, consisting of parallel disks with flat wooden paddles between them driven by a free jet. In 1866 the Pacific Iron Works produced a cast-iron unit with curved blades for the Gwin Mine in Calaveras County, in the hope that this form would lead the water away from the zone of impingement more effectively. Four years later S. N. Knight of Sutter Creek patented a wheel with cup-shaped buckets, and three years after that Nicholas J. Colman obtained patent rights on a splitter bucket, but he did nothing further with it. Then in 1880 a millwright from Nevada City, California, by the name of Lester Allen Pelton (1829-1908) took to the firm of Brayton and Dodd in San Francisco a split bucket of his own design. To quote from his 1897 pamphlet *Origin of the Pelton Water Wheel*,

> I crossed the plains from [Vermillion] Ohio in 1850 and engaged in mining almost continuously until 1864, when I took up millwrighting, in connection with mining, at Camptonville, Yuba County, and other places north of that town, in which business I was employed until 1878; and during that period I constructed a number of waterwheels, having an efficiency of 40 per cent, and

> upwards, according to the type of buckets used. Here, I conceived, was a chance for improvement; and early in 1878 I procured the necessary appliances for testing the efficiency of buckets for pressure- or jet-wheels, and devoted most of the time for two years following to designing a bucket which would give a higher efficiency. I tested between thirty and forty different shapes of buckets, and finally noticed that a curved bucket having a jet-strike on the side, as in Fig. 11b, instead of its center (Fig. 11a), gave a marked increase in the efficiency of the wheel, but caused an endthrust against one bearing. To avoid this, I experimented with placing the buckets alternately, as in Fig. 12, when it was but a step to combining the two curved buckets and splitting the stream, as in Fig. 13. This bucket, when tested, gave such astonishing results that I immediately took steps to secure my invention.
>
> I introduced my wheel to the public, after obtaining a patent, in October, 1880, and claim to have invented what is known as the "Pelton Water-wheel" independently and without any knowledge whatever or aid from the efforts of others in that line.

For his invention, Pelton was eventually awarded the Elliott Cresson Medal of the Franklin Institute.

Though Dodd was the member of the Brayton-Dodd partnership who was first approached by Pelton, it was Brayton and his son who formed the Pelton Water Wheel Company to manufacture and market Pelton's patent. When Dodd tried in retaliation to patent a similar device of his own, he was informed that it infringed upon the earlier patent of Colman's. He thereupon purchased the rights from Colman and later sold them for a good price to the Pelton Company. Before debating the matter of priority between Colman and Pelton, it is pertinent to note that from 1865 to 1868 Joseph Moore of the Risdon Iron Works of San Francisco had consulted with Frederick Godfrey Hesse (1825-1911), a German-born engineer of San Francisco, who had at that time provided original sketches (reproduced from memory in an 1897 communication to Pelton) of a split bucket; in 1874 Moore in turn had submitted sketches (still existing) of split-bucket wheels to a client. In 1875 Hesse became Professor of Industrial Mechanics at the University of California; it is hence interesting to note that whereas Pelton experimented first in the field, with buckets improvised from oyster cans, a model made from patterns supplied by Pelton had been tested by 1883 in Hesse's laboratory at the University. Pelton took out a second patent in 1889 on small details, and this was followed by many others, notably those by William A. Doble in 1899 on improvements in the bucket and in 1900 on the first needle nozzle. The Pelton and Doble

Companies joined in 1912 under the Pelton name, with Doble as chief engineer.

Since the aforementioned tests at the University of California were made in what appears to have been the first hydraulics laboratory for instructional purposes in the United States, further comment is well merited at this point. Unfortunately, all that is known about the laboratory is to be found in a printed report by three students of Professor Hesse, supplemented by a colleague's description of the efficiency tests on the Pelton unit. Published at Berkeley by the College of Mechanics in June 1883, the opening paragraph contains the statement:

> The water wheels, pressure gauge, etc., used in these experiments are made a part of the permanent outfit of the Experimental Department of the Mechanical Laboratory. It is the intention to equip this department largely in such a manner as this paper will suggest.

How many years before 1883 the laboratory was established will probably never be known. However, the publication attests not only to its prior existence but also to the high quality of the experiments conducted in it. The model Pelton wheel on which the tests were made is still in the possession of the College of Engineering at Berkeley.

At this point brief note might well be taken of the fact that application for Patent No. 344,878 on a sluiceway gate was made on 16 November 1885 by Jeremiah Burnham Tainter of Menomonee, Wisconsin, as announced in the *Official Gazette* for 6 July 1886, the date of patent issue. Nothing further is known about Mr. Tainter except for the fact that he definitely did not spell his name with the "o" sometimes found in handbooks. (The sector type of gate, on the other hand, is known to have been sketched by Leonardo da Vinci some four centuries earlier.)

Charles Hermany (1830-1908), of Lehigh County, Pennsylvania, was the next of the many noteworthy hydraulic engineers of the late 19th century whose activities continued well into the 20th. He was largely self-educated, and most of his professional life was spent with the waterworks of Louisville, Kentucky. There he conducted experiments to determine the best methods of filtering river water to eliminate traces of sewage and other impurities. In 1875 he demonstrated the practicability of rapid filtering on an extensive scale, coagulant being added to filters set directly over clear-water reservoirs. He was also a consultant to neighboring cities, and—like many a colleague—was honored with the presidency of the ASCE. John James Robertson Croes (1834-1906) of Yonkers, New York, was another hydraulic engineer who learned his profession by doing. After obtaining railroad experience in New Jersey, he was selected by Kirkwood as assistant engineer on similar projects including the Croton. His expertise in the field of water supply took him to Washington, Cincinnati, St. Louis, Newark, and back again to the Croton development for New York. In addition to serving as president of the ASCE, he not only received its highest award, the Norman Medal, for an 1874 paper on construction of a masonry dam for the Croton Aqueduct Board, but was honored by having his name connected with the second highest, the Croes Medal, both of which have since been awarded for many papers in hydraulics as well as other civil-engineering fields. Contemporary with Croes was Joseph Palmer Frizell (1832-1910), born in Canada of Vermont parents and also self-educated as an engineer. He assisted James Francis at Lowell both before and after the Civil War, and then became a consulting hydraulic engineer. Frizell's interest in turbines was reflected in his 1900 book, *Water-Power,* the first practical work on the general subject, as well as a number of related papers for the ASCE. His writings were notable for his facility with infinitesimal calculus.

One who played a leading role in both hydraulic experimentation and sanitary research was Hiram Francis Mills (1836-1921) of Bangor, Maine. Mills obtained a bachelor's degree from Rensselaer and a master's from Harvard, and then was so fortunate as to serve as assistant engineer with Charles Storrow (stream gaging), James Kirkwood (tunnel construction, waterworks development, and power measurement), and James Francis (mill construction at Lowell) before opening his own consulting office at Boston in 1868. A year thereafter he was employed as chief engineer by the Essex Company at Lawrence, where he proceeded to develop a new laboratory for large-scale tests, followed in a few years by still another. Particularly noteworthy were his measurements of the velocity distribution. He modified the Darcy Pitot tube by moving the static opening to the wall of the conduit (after Bernoulli) and placing the dynamic opening at the leading edge of a cylindrical tube held normal to the flow. As many as 20 openings were so used on a 1-inch pipe spanning a 9-foot conduit, and the manometers were interconnected at the top so that their common reference level could be conveniently raised or lowered. Pipes with single openings were rotated to determine the direction of flow (i.e. midway between positions yielding the same reading). He also investigated the error introduced by the faulty construction of piezometers, including protrusion and inclination. Many original studies were made of weirs, pipes, and open channels, but their publication was postponed indefinitely by Mills' becoming a member of the Massachusetts Board of Health in 1892 and proceeding to develop the Lawrence Experiment Station to study methods for purifying water and treating sewage. Only 8 miles down the Merrimac River from the sewer outfalls of Lowell, the station was in an ideal place for practical investigations, and it attracted widespread attention. There Mills developed many young associates like Edmund Brownell Weston (1850-1916), George Chandler Whipple (1866-1924), George Warren Fuller (1868-1934), and Allen Hazen (1869-1930), who eventually spread over the United States. In 1886 Mills became a consultant on the improvement of the Charles River as well as the sewer system of Boston and, in 1894, chief engineer as well to the Lowell Proprietors. Though he never headed the ASCE, he was elected an honorary member, and also a member of the MIT Corporation. A paper that he had written on the flow of water in pipes was published posthumously by the American Academy of Arts and Sciences.

Another in the group of water-supply engineers was John Thomas Fanning (1837-1911) of Norwich, Connecticut. Educated at Norwich, he designed and built supply systems in various parts of New England, consulted on others in New York, Chicago, and Minneapolis, and—like Francis—was involved in the St. Anthony Falls power development as well as similar works as far west as the Pacific Coast; he also served a term as president of the American Water Works Association. Fanning's principal accomplishment so far as the present discussion is concerned was the publication in 1877 of *A Practical Treatise on Hydraulic and Water Supply Engineering,* a text and reference book which probably had the greatest circulation in its field of any in this country: 16 successive editions in 30 years. It was a volume of more than 600 pages, its 25 chapters being divided into three parts: 9 on hydrology, 6 on hydrodynamics (i.e. hydraulics), and 10 on waterworks. In a simple style replete with wisdom as homely as Ewbank's, the author did his utmost to provide the reader with the knowledge necessary to design hydraulic systems. The hydraulics section helped crystallize the method of presentation that was to be followed by subsequent writers for many years: hydrostatics, orifices, tubes, pipes, weirs, and open channels, with comparative tabulations of coefficients that had been determined in each case by as many as a dozen investigators. Resistance equations of Du Buat, Prony, Eytelwein, and Weisbach were frequently used, but not only was no use made of the Bernoulli relationship—Bernoulli was not even mentioned. In the construction section, a primitive method of analyzing pipe networks was given, but with no indication of handling more than one line at a time. The book closed with tabular matter relating to the metric system (the gramme being a unit of weight!) and advice on means of resuscitation from death by drowning.

Alphonse Fteley (1837-1903), a native of France, migrated to the States in 1836 and engaged in the development of waterworks systems for Boston, New York, and other major cities. At Boston a young engineer from Maine named Frederic Pike Stearns (1851-1919) attracted his attention (as well as that of Storrow and Francis) and became his assistant in the engineer corps of the Boston Water Works. A joint paper by Fteley and Stearns in the 1883 *Transactions* of the ASCE described their numerous experiments in the new Sudbury Conduit on weirs as measuring devices, which won them the Norman Medal of the Society (of which Fteley, and later Stearns, was to serve as president). The prize-winning paper dealt with weirs of various crest shapes (sharp, rounded, and broad) and degrees of submergence. Even more empirical than the earlier work of Francis, it stressed the role of the velocity of approach and was probably responsible for the emphasis laid on this factor (actually only a part of the geometric effect) in the subsequent American literature. Stearns wrote several other papers on hydraulics and sewerage, recommended damming the Charles River in his plan for the sewage system of the Mystic and Charles Valleys, and was also elected president of the Boston Society of Civil Engineers.

Still another hydraulic-textbook writer, though not primarily a civil engineer, was Hamilton Lamphere Smith (1840-1900) of Louisville, Kentucky, who had learned engineering in his father's mines. He moved to the Pacific Coast in 1869 to engage in the placer mining of gold; there he built dams and pipe systems and became the California authority on hydraulics. His book *Hydraulics, the Flow of Water through Orifices, over Weirs, and through Open Conduits and Pipes,* was published in 1886, and he wrote in addition three ASCE papers on the subject. His later professional career took him to Mexico, Venezuela, and South Africa. The book—362 9x12-inch pages—was noteworthy for the numerous original experimental data (corresponding to the flow of oil and mercury as well as water) which it contained in addition to those regularly quoted from other experimenters. Many of them stemmed from his activities in California, but the most recent were obtained in Holyoke, Massachusetts. Smith's carefully plotted data disclosed coefficient trends now attributed to viscous and capillary effects.

Clemens Herschel (1842-1930), "the man who made Venturi famous," was born in either Vienna or Boston, probably the latter. He entered Harvard's Lawrence Scientific School at the early age of 16 and after graduation went to France with the intention of enrolling in the *Ecole des Ponts et Chaussées* at Paris. But its foreign quota was already filled, and he studied instead in the *Technische Hochschule* in Karlsruhe, Germany, which later (1925) bestowed on him the honorary doctorate of engineering. On his return to the States Herschel opened a Boston consulting office, and at the beginning he engaged principally in bridge construction. Then, in the belief that there was no future independence in structures, and having enjoyed working for a time with James Francis, he accepted in 1879 a position as hydraulic engineer with the Holyoke Water Power Company. There one James Emerson, previously attracted from Lowell by the offer of free water for turbine testing, had built a flume in which competitive efficiency tests were held the year Herschel joined the organization. The latter proceeded to build a new flume with flows up to 200 cubic feet per second under heads of 18 feet for determining more precisely the efficiency of the 139 turbines in the neighboring factories; the rates at which water was used thereafter were evaluated from daily records of their gate openings. However, to use his own words,

> There was another draft of water out of the canals, unseen by human eyes, which sorely troubled me. This was the large quantity used by the manufacturing corporations, including some 25 large paper mills, as washwater; roughly estimated at 10 per cent of the quantity used for power. This water was drawn through cast-iron pipes, most of them 20 to 24 inches in diameter, painted black on the outside, and they lay there, usually in the basement of the mill, silent as the grave, and most provokingly secretive of what was passing within their interior. Many a time did I stand beside such a pipe and exert myself to invent how to force these pipes to reveal the secret of their hidden action.
>
> These endeavors resulted in a determination at the first opportunity to try how an apparatus like this would work: place an orifice at some point of the pipe, circular and in the form of an ajutage, from choice, and then place an expanding cone downstream from the orifice, in order that the loss of head occasioned by the first orifice may be regained, and no material loss of head be occasioned by the whole apparatus.

As Herschel himself noted, the basic ideas of the device which he perfected were all available in the literature, from Bernoulli's and Venturi's indications of the pressure drop at the throat to Francis' studies of the proportion to be used in the divergent section in order to produce a minimum loss of head. But it was Herschel who first combined these ideas into a meter for discharge measurement. The naming of the instrument appears to have resulted from the practice in his laboratory of calling the reading of the throat pressure "the Venturi," and Herschel let the term remain. He characteristically noted that the Bernoulli principle was not applied to the theoretical determination of the meter coefficient until after the device had been tested:

> We have thus seen that an understanding of the correct principle according to which an invention operates, may follow, instead of precede, the making of an invention; indeed such understanding may come to the inventor last of all; provided he do but sufficiently cogitate and experiment.

For this 1887 paper describing "The Venturi Water Meter," from which the foregoing material has been quoted, Herschel received the

Thomas Fitch Rowland Prize of the ASCE; in 1899 he was awarded the Elliott Cresson Medal of the Franklin Institute for his invention. Ten years earlier he had left his beloved Boston to become chief engineer of the East Jersey Water Company, which supplied Newark and neighboring cities. There the Venturi meter saw its first extended use, and it has since been adopted in various sizes throughout the world—most notably on the Catskill Aqueduct supplying New York City. Herschel was the only American on the board of five engineers which recommended the use of Swiss turbines for Niagara Falls power, and thereafter he became an engineer with the Allis-Chalmers Company to improve American units. When Allis-Chalmers moved to Milwaukee, he resigned rather than leave the East. Not only did he act as consultant on many municipal projects, but in 1899 he published *The Two Books on the Water Supply of the City of Rome of Sextus Julius Frontinus* which he had translated from the original Latin (with the aid of existing versions in French and German); his scholarly commentary was fully twice as long as the text! He was also the author, in 1897, of "115 Experiments on the Carrying Capacity of Large, Riveted Metal Conduits," and of countless articles and discussions. In the course of his active life Herschel served as president of both the BSCE and the ASCE, and each elected him to honorary membership. In an early version of his will he left $50,000 to Harvard University for the establishment of a hydraulics laboratory once the sum had grown to $500,000, but the latter restriction (so reminiscent of Franklin) was later modified. To quote his will:

> For many years I have endeavored to aid in the establishment of an endowed hydraulic observatory in which the study of applied practical hydraulics could be pursued experimentally in a continuous manner by skilled workers and observers . . . the study of theoretical hydraulics having proved a wholly barren field for several centuries, and of about as much use or application as the work of a certain German professor who spent his whole life in translating the Latin classics into ancient Greek. . . . With these views in mind, I have sought to induce a number of engineers to make bequests similar to mine to Harvard College. . . .

Another 19th-century engineer with German training was Rudolph Hering (1847-1923), a native of Philadelphia who obtained both his secondary and higher education at Dresden—also receiving the honorary German doctorate for his later accomplishments. He too first built bridges, but then became assistant city engineer for Philadelphia sewers as well. As such he was sent back to Europe by the National Board of Health to study sewerage practice, and his 1881 report on the tour has become a classic. From 1882 to 1888 he was engaged on three noteworthy projects: the water supply of Philadelphia; planning of the Chicago Drainage Canal to prevent further pollution of Lake Michigan; and improvement of the sewerage of New York City, where he was to maintain a consulting practice for the next 30 years. He was a member of the Hering-Freeman commission whose report led to the Catskill Aqueduct. He readily accepted the germ theory of disease and was a strong proponent of mechanical filters. His sanitary-engineering counsel was sought by many cities both here and abroad. With a younger colleague, John Cresson Trautwine Jr (1850-1924), he translated and published in 1893 the work of Ganguillet and Kutter under the title *A General Formula for the Uniform Flow of Water in Rivers and other Channels,* which went through several editions. (A translation of Kutter's earlier articles, it should be noted, had been published in England in 1876 by Lowis d'A. Jackson.)

Mansfield Merriman (1848-1925), who was born in Connecticut, was to play a leading role in various branches of engineering education, not the least of which was hydraulics. He was widely read by the time he entered Yale University's Sheffield Scientific School, where he obtained the PhB and CE degrees, and then the PhD following a 6-month interim in Germany. After instructing several years at Yale, he joined the staff of Lehigh University and for the next 30 years took the lead in establishing its reputation for the training of engineers. He published extensively in mathematics, mechanics, sanitation, surveying, and structures; his *Treatise on Hydraulics* of 1889 went through 10 editions and was followed in 1912 by *Elements of Hydraulics.* Though clearly written and carrying the subject matter logically to power machinery and even naval hydrodynamics, the *Treastise* was the work of a pedagogical generalist rather than a specialist in hydraulics, and it now seems to fit the stereotype of all-too-many predecessors and successors. A plaque on the Lehigh campus still commemorates what is called the "first hydraulics laboratory under college auspices in America": a small building (records disagree as to its size and newness) supplied by a brook with a flow of 10 to 15 cubic feet of water per minute, in which demonstration experiments were conducted on orifices and weirs; first occupying the site in 1886, the building was removed in 1895. (As has already been noted, Hesse's laboratory at California antedated it by at least four years.) Merriman was a founder and president of the Society for the Promotion of Engineering Education and also of the American Society for Testing Materials.

Probably the engineer who had the most profound and lasting effect on American hydraulics was John Ripley Freeman (1855-1932), a thoroughgoing Yankee from West Bridgton, Maine. After graduation from MIT, Freeman was engaged by the Essex Company at Lawrence, where he assisted Hiram Mills for 10 years—an experience which he remembered gratefully throughout his long and effective life. In 1886 Freeman became an engineer for the Associated Factory Mutual Life Insurance Companies, but arranged to spend half of his time as a private consultant. During this period he published two noteworthy papers: "Experiments Relating to Hydraulics of Fire Streams" (1889), an extensive coverage of hoses, fittings, nozzles, and the throw of jets; and "The Nozzle as an Accurate Water Meter" (1891), a shorter sequel; for each of these he received the Norman Medal of the ASCE. Freeman also made measurements in 1892 for the purpose of studying the flow in pipes supplying automatic sprinklers; these were not published till well after his death, which is indeed unfortunate in view of the accuracy (seldom exceeded even today), scope (to Reynolds numbers of nearly 900,000), and innovativeness (for example, the use of artificial roughness) of the experiments. Freeman moved to Providence in 1896 to become president of the Manufacturers Mutual Fire Insurance Company, where he remained till his death. Extremely active till the end, he wrote and consulted not only on experimental hydraulics and insurance but also on earthquake protection, water power, sanitation, river control, water supply, and conservation. As a consultant he traveled extensively abroad: Italy (flood control of the Po River, for a paper on which he received the ASCE Croes Medal); Panama (in connection with the planning of the Canal); and China (improvement of the Grand Canal and the Yellow River). In the States he was involved in particular with the Charles River Basin of Boston and (with Hering) the water supply of New York. Long a member of the MIT Corporation, he was once offered the MIT presidency, but declined it in the belief that he was better fitted for engineering practice. He did serve as president of the BSCE, the ASCE, and the ASME, and was elected to honorary membership in all three. While this is sufficient accomplishment for any man, the principal basis for his influence on American hydraulics will be reserved for discussion in a subsequent chapter.

A fitting close to this review of the late 19th century is the story of the formation of the Water Resources Branch of the United States Geological Survey. The USGS itself was preceded by a series of federally sponsored surveys, established in succession just after the Civil War and known by the names of the men who led them: King, Hayden, Powell, and Wheeler. The first and fourth of these were funded by the War Department (under General Humphreys, then Chief of Engineers) and the second and third by the Department of the Interior. All had the general task of providing geological and topographical maps and related information for specific portions of the western United States. The situation being what it was, a rather bitter rivalry developed between the representatives of the two departments, and Congress finally sought the advice of the relatively new National

Academy of Sciences as to an effective means of combining the groups. Though the War Department claimed that it could best handle the unification, at the Academy's recommendation Congress established the USGS under Interior auspices in 1879. Clarence King, the compromise first director, resigned in favor of John Wesley Powell (1834-1902) after just two years of service. Nine years later a division known as the Irrigation Survey was formed to investigate the possibility of irrigating essentially one-half of the United States! As a subdivision thereof, the Hydraulic Survey was formed to measure the water supply of the regions to be irrigated.

That year Powell obtained the services of a young graduate from MIT named Frederick Haynes Newell (1862-1932), whom he very shortly placed in charge of a stream-gaging camp at Embudo, New Mexico, to train engineers to carry on similar work elsewhere. The methods of Ellet, Marr, Humphreys and Abbot, and others were applied, and new instruments and practices were developed. Seven years later (1895) the Survey adopted the current meter patented in 1885 by William Gunn Price (1853-1928), an engineer-inventor with the Mississippi River Commission; hydrodynamically the instrument was a monstrosity, for it would register even if simply moved up and down; but it was rugged, not easily fouled, and possessed of bearings operating in air pockets and hence comparatively trouble-free in silty water. Though the Irrigation Survey was terminated in 1890 and its financial support cut off, Newell was transferred to the topographic payroll and still managed to continue his hydrographic work, but on a greatly reduced scale. The appropriation for stream-gaging was restored in 1894, and two years later the publication of *Water-Supply Papers* was authorized. Congress finally passed a much-needed Reclamation Act in 1902, and the newly organized Hydrographic Branch, with Newell as chief hydrographer, began to expand. When in 1907 the Reclamation Service was made a separate bureau within the Department of the Interior, Newell was named its first director and necessarily left the Survey. At much the same time the name of his former branch was changed from "Hydrographic" to "Water Resources" in the hope of gaining greater congressional recognition. Nevertheless, financial support began to drop, and only through the funding of cooperative stream-gaging agreements by other federal services and individual states—already including four in the Middle West—was sufficient financial support obtained.

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CHAPTER IV

FURTHER LABORATORIES AND TEXTBOOKS

As may be judged by the title of this chapter, it will reflect in large measure a continuation of trends that had already come into existence. The development of laboratories, both large and small, at Lowell, Lawrence, Holyoke, Boston, Bethlehem, and Berkeley has been noted. Books by Allen, Bigelow, Renwick, Storrow, Francis, Ewbank, Fanning, Merriman, and Smith have been commented upon in more or less detail. In each case it was the men involved as much as their contributions which were of interest: their backgrounds as well as their influence on colleagues and successors. The latter relationship is particularly significant in the case of the last individual discussed—John R. Freeman—and an entire chapter will be devoted to this. As the time of writing is more closely approached, an added factor can be introduced—personal characteristics as recalled by people still alive who actually knew those under consideration.

Three years after passage of the Morrill Land Grant Act (though not dependent upon it), there was established in Worcester, Massachusetts, the Free Institute of Industrial Science, the name of which was changed in 1887 to Worcester Polytechnic Institute. Prominent among the initial faculty was George Ira Alden (1843-1926), then a recent graduate of Harvard's Lawrence Scientific School, who taught physics and drawing and was generally responsible for both civil and mechanical engineering. As the result of an idea expressed by Alden at an alumni dinner in 1893, the Institute received the gift of 200 acres of land at Holden, a town just north of Worcester, on which were located a number of ponds. The gift included the water rights, a Fairbanks scale (matching one obtained by the Institute from the 1876 World's Fair), and a 36-inch Venturi meter (then the largest in the world) from the Fair of 1893. These were assembled with a copper-lined weighing tank in a one-story building on the former mill site, and for the next two years Professor Alden was in charge of a hydraulic laboratory that has continued to be active ever since. For a long time this activity was provided by an 1894 graduate in mechanical engineering, Charles Metcalf Allen (1871-1950), who was to display just as strong Yankee tendencies as had John R. Freeman. Moreover, he soon developed a knack for acquisition, whether through client firms or through benefactors like Alden himself after he had left the Institute for the more lucrative presidency of the Norton Company, a manufacturer of abrasives. In 1908 Alden donated a meter station; in 1915 the laboratory was named for him; and some ten years later he gave it a brand new building that is still in use.

Eventually known by students and junior staff as "Prof," Allen developed a pithy style of lecturing and writing. His teaching philosophy is well revealed by the following observations that he was accustomed to make:

> If you stay with a problem long enough you will get the answer. It may not be the one you expected but the chances are it will be the truth.
>
> If you really want to learn anything from an experiment, change only one condition at a time.
>
> Never hesitate to try a hunch. If it turns out O.K., the theoretical fellow will tell you why.
>
> If practice and theory don't agree, investigate the theory.

Allen will be especially well remembered for his comparison of turbulent mixing with the passage of a flock of sheep down a country road lined on both sides with attractive vegetation. As the automobile came into use, he began to give a cautionary talk on "Gasoline, its Uses and Abuses," which proved so popular (what with explosions, fire-eating, and all) that he continued to give it for many years. And until the end he took delight in demonstrating that the old Fairbanks scales were sensitive to as little as a 50-cent piece. For most of his professional career Allen taught half-time and consulted half-time, bringing many a contract for testing and calibration (and eventually for spillway and other models) to the Alden Laboratory. However, his name will always be most closely associated with the salt-velocity method of discharge measurement for the evaluation of turbine performance. The idea that was involved—timing the progress of an injected cloud of saline solution along a conduit—began to take shape in 1921, and it was formally presented in the 1923 ASME *Transactions* paper by Allen and Taylor. A vast change is evident between the first exploratory tests (with raw salt even) in the 400 feet of 40-inch riveted pipe on the laboratory grounds and the refined combination of injectors, electrodes, and recorders eventually adopted.

Of more than passing interest is the coincidental appearance in the same volume of *Transactions*—immediately following the Allen paper, in fact—of the paper "The Gibson Method and Apparatus for Measuring the Flow of Water in Closed Conduits," by Norman Rothwell Gibson (1880-1967), a hydraulic engineer of the Niagara Falls Power Company. In use since 1920, this method was based on the impulse-momentum principle, the difference in pressure between two piezometers at successive longitudinal positions along a penstock being recorded against time as the rate of flow was brought to zero. Two new and fundamental methods of discharge measurement were thus presented almost simultaneously. Clemens Herschel, in vigilant defense of the Venturi meter, noted in his discussion that both methods yielded merely spot indications rather than a continuous record with time. (At this point it might well be remarked that a third method—salt dilution—had been described in 1916 in the ASCE *Transactions* article, "Chemi-Hydrometry and its Application to the Precise Testing of Hydro-Electric Generators," by Benjamin Feland Groat (1867-1949), a consulting hydraulic engineer of Philadelphia. As Groat himself noted in his rather verbose style, the method of measuring rates of flow by noting the dilution of an injected chemical solution had been proposed in France as early as 1836 and been used for determining small rates of flow in both Switzerland and England. His contribution was its application to flow rates several orders of magnitude greater.)

Initial hydraulics-laboratory development at Cornell University (where many of the leading hydraulicians of the country were to study or teach) appears to have resulted from the activities of two men. One was Estevan Antonio Fuertes (1838-1903), a Puerto Rican who was educated in Spain and then involved in such projects as the Croton Aqueduct and canal surveys in Panama before becoming dean of civil engineering at Cornell. In 1880 the Trustees appropriated $100,000 to equip certain departments of the University, and Fuertes thereupon revisited Europe to study pedagogical laboratory practice. The other man was Irving Porter Church (1851-1931), a Cornell graduate who had been on the teaching staff in applied mechanics and hydraulics since 1876 and who was to become widely known for his *Mechanics of Engineering*, one volume of which *(A Treatise on Hydraulics and Pneumatics)* was devoted to fluids; superior to many later imitations, it gave considerable attention to the Bernoulli theorem; the work of Weisbach, drag, wind pressure, and the flow of gases, and it even included mention of Reynolds and Froude. When the civil engineering department moved into Lincoln Hall in 1889, one end of the basement was used as a modest hydraulics laboratory for instructional purposes under Church's direction. In 1896 the Trustees made a special appropriation of $60,000 for the construction of separate laboratory facilities at the end of Beebe Lake. Terminating in a dam followed by an overall drop of 185 feet, this provided pondage of some 20 acres and a minimum flow of 12 cubic feet per second. From the lake there eventually led a 16-foot channel 420 feet in length and provided with a towing car having a maximum speed of 12 feet per second. When completed, the laboratory building, confined on one side by a cliff and on the other by Triphammer Falls, was to contain a smaller flume, pumps, and turbines.

The first active director of the laboratory was Gardner Stewart Williams (1866-1931), a Michigander by birth and education, who went to Ithaca in 1898 as professor of hydraulics from his position as engineer of the Detroit Water Commission. While at Detroit he had conducted, with two colleagues, an extensive series of tests on pipe resistance, a paper on which appeared in the ASCE *Transactions* of 1902 and won the Norman Medal. At Cornell he persuaded two of his graduate students, Augustus Valentine Saph (1871-1920) and Ernest William Schoder (1879-1968), to carry out additional tests, and these were published by the ASCE the following year. The extensive discussion of the two papers, a *Transactions* tradition, throws much light on both the people and the times. Investigations which Williams himself conducted in the still-incomplete laboratory facilities involved studies of flow over large (4- to 6-feet-high) model dams for various agencies. These included many angular crest forms for the U.S. Deep Waterways Board under the direction of George W Rafter (1851-1907); the old Croton dam profiles under John R. Freeman; and various shapes of U.S. Geological Survey measuring weirs under Robert Elmer Horton (1875-1945). All of these tests were described in 1906 in Horton's Water Supply Paper 150, *Weir Experiments, Coefficients, and Formulas,* which also reviewed all known literature on the subject.

When Williams went back to Michigan in 1904 as head of civil engineering, he was replaced in the Cornell laboratory by Schoder, by then a holder of the Cornell doctorate, who was to remain in charge of laboratory operation for the next 40 or more years. In the face of frequent lack of funds, Schoder often did his own carpentry and plumbing, but he and his students produced many experimental results. It is noteworthy that the Saph-Schoder pipe-flow data already mentioned were the ones used by Prandtl's pupil Heinrich Blasius in 1913 to construct the first Reynolds-number resistance diagram. During the development of the Gibson method in 1920, Schoder provided the volumetric measurement needed for comparison purposes. Prominent in the hydraulics literature of 1929 was the ASCE paper "Precise Weir Measurements," by Schoder and Kenneth Bertrand Turner (1882-1918), reviewing the many weir experiments that had been in progress since Turner completed his master's thesis in 1905.

While still at Cornell, Williams developed with Allen Hazen of New York, mentioned above as one of Hiram Mills' protégés, a wholly empirical formula for flow in pipes which they considered the best fit to the recorded measurements of several dozen experimenters on nearly a dozen types of pipe of many sizes. This was published in the *Engineering Record* of 28 March 1903 with the following ingenuous commentary:

> Kutter's formula was devised to compute the value of c in the Chezy formula [$v = c\sqrt{rs}$]. The value of c so computed depends upon an assumed coefficient of roughness, upon the slope, and

> upon the hydraulic radius. With the same degree of roughness the value of c increases with the hydraulic radius. This is because the exponents used for these terms in the formula are below the true values. If the exponents were increased to correspond more nearly with the facts, the variations in the value of c would become less. If exponents could be selected agreeing perfectly with the facts, the value of c would depend upon the roughness only, and for any given degree of roughness c would then be a constant. It is not possible to reach this actually, because the values of the exponents vary with different surfaces, and also their values may not be exactly the same for large diameters and for small ones, nor for steep slopes and for flat ones. Exponents can be selected, however, representing approximately average conditions, so that the value of c for a given condition of surface will vary so little as to be practically constant. Several such "exponential" formulas have been suggested. These formulas are among the most satisfactory yet devised, but their use has been limited by the difficulty in making computations by them.

The authors claimed to have eliminated this difficulty by placing a special slide rule on the market, and in 1905, after Williams had moved to Ann Arbor, they also published the small book *Hydraulic Tables,* which presented solutions to the power equation in tabular form. Despite its dimensionally illogical nature, the Hazen-Williams formula was probably the most practical means then available for estimating the magnitude of boundary resistance, and as such it was eagerly seized upon by hydraulic engineers. In the long run, however, it is debatable whether it did more good or harm, for it not only concealed the principles behind the resistance phenomenon but made acceptance of later, more rigorous analyses like that of Blasius a very slow process.

Although the Agricultural College of Colorado was established at Fort Collins as a land-grant institution in 1870, its early development was rather slow — due in no small measure to the complete dependence of local agriculture on irrigation, which was still at a very primitive stage. In 1882 Elwood Mead (1858-1936), a Hoosier and Purdue graduate, was employed by the college as instructor in mathematics, yet it was not long before he was teaching courses in the control and measurement of flowing water. By 1886 he was professor of irrigation engineering, but only two years later he left for Wyoming and great subsequent accomplishments with federal bureaus (including appointment as Commissioner of Reclamation), in honor of which the lake above Hoover Dam now bears his name. In 1893-94 a small instructional laboratory was developed at Fort Collins in the basement of the engineering building. Among the graduating class of 1904 was Ralph Leroy Parshall (1881-1959), who joined the faculty in 1907 and thereafter (1912) designed an irrigation laboratory. A year later he became an irrigation engineer with the U.S. Department of Agriculture, stationed there at Fort Collins and continuing to work closely with the college. By 1922 he had patented the adaptation of the Venturi flume known by his name. Associated with Parshall in later years was Carl Rohwer (1890-1959) of Nebraska and Cornell, who had been with the USDA in various localities since 1920 and whose particular interests were seepage and evaporation.

Paradoxical as it may seem to start this series of American textbooks with reference works for practicing engineers on the one hand and the product of a Canadian on the other, neither is really out of place. In 1885 Augustus Jesse Bowie, a mining engineer, published *A Practical Treatise on Hydraulic Mining in California.* The book was exactly what its title implied: a compilation of everything hydraulic that would be of use to miners—a discussion of reservoirs and dams, flow measurement, ditches and flumes, pipes and nozzles, wheels, etc. The hydraulics itself was largely a tabulation of coefficients. Patrick John Flynn (1838-1893), a Californian who had been with the Public Works Department in the Punjab, India, published in 1886 a small pocket book of hydraulic tables, followed in 1892 by an all-inclusive tome of 681 pages on *Irrigation Canals,* which he hoped would be useful to engineering students. And *A Treatise on Hydraulics,* by Professor Henry T. Bovey of McGill University, Montreal, was published in New York in 1895 and could well have had a salutary influence on writers in the States: hydrostatics was omitted; Bernoulli's theorem was introduced on page 6; the treatment of fluid dynamics was knowledgeable (though the flow patterns were as poorly conceived as most others); many of the coefficients had been determined at McGill; about one-third of the text dealt with hydraulic machinery; and it contained problems by the hundreds. Five years thereafter, Marvin E. Sullivan published *Sullivan's New Hydraulics,* the Preface of which contained the following optimistic words:

> When the student of hydraulics investigates and compares the conflicting theories of flow and of the variation of the coefficient as set forth in the old formulas, he is simply bewildered and discouraged, for he can discover no satisfactory reason for adopting any one of them in preference to another. The writer therefore hopes to be pardoned for offering what he conceives to be the rational solution of these difficulties.

The rest of the text was less than promised. Whereas the author proved to be a good critic—particularly in the choice of reliable data for pipes and open channels—he was creatively ineffectual, merely belaboring the resistance equations and their coefficients.

Though not a book, a work published in 1900 by James Alexander Seddon (1856-1921) was to be quoted by many a text in subsequent years. This was his ASCE *Transactions* article on river hydraulics containing what has come to be known as Seddon's Law, apparently formulated independently though first published in France by Kleitz in 1877. A simple application of the continuity principle, it states that a moderate increase in discharge imposed upon an approximately steady flow produces an increase in stage which travels downstream as a monoclinal wave at a celerity that is equal to the slope of the rating curve—i.e. discharge versus stage—divided by the surface width. The relationship was discovered and checked experimentally during Seddon's study of flood movements on the Mississippi and Missouri Rivers, and it marked the beginning of American analysis of unsteady open-channel flow. Four years later, Captain David Du Bose Gaillard (1859-1913) of the Corps of Engineers published a report on *Wave Action in Relation to Engineering Structures:* this not only summarized the literature from the time of Gerstner on, but it presented his observations of wave profiles, periods, celerities, and orbital movements, as well as actual wave-pressure measurements by spring and diaphragm dynamometers; he evidently did not understand the difference between dynamic and true-impact pressures.

The year 1906 brought a most interesting occurrence, especially for that time in our history. An ASCE paper on the new filtration plant at Washington DC by Allen Hazen and a colleague contained original information on the flow of sand and water in pipes. One of the written discussions was prepared by a young lady of English birth named Nora Stanton Blatch (1883-1971) based on experiments which she had conducted at the Cornell laboratory while studying for the first civil-engineering degree to be received in the United States by a member of her sex. Several grades of sand and 1-inch brass and galvanized pipes had been used by Miss Blatch, and she sought to correlate her results with the authors' tests on 3- and 4-inch pipes and those of the Mississippi River Commission on 30-inch dredge lines; in particular, an effort was made to estimate the velocity at which, over the range of these data, any sand could be carried in any pipe with minimum power expenditure per unit volume. (Miss Blatch thereafter continued her activity in both engineering and woman suffrage; in addition, she became the first wife of Lee de Forrest, self-termed "father of radio broadcasting.")

In comparison with much that preceded and followed, the 1906 work of Leander Miller Hoskins (1860-1937), a professor of applied mathematics at Leland Stanford Junior University since 1892, was most refreshing. Entitled *A Text-book on Hydraulics Including an Outline of the Theory of Turbines*, it was straightforward, uncluttered by needless detail, relatively free from tabulations of experimental data, and fully in keeping with the following excerpt from the Preface:

> It is perhaps not too much to say that the key to correct understanding of all problems in the steady flow of liquids is supplied by Bernoulli's theorem—or, as it is usually called in the text, the general equation of energy.

Despite the inclusion of material on the theory of both turbines and pumps, the original volume and its subsequent editions remained a compact forerunner of much to come. Of a considerably different nature was the 1907 book *River Discharge: Prepared for the Use of Engineers and Students*, by John Clayton Hoyt (1874-1946) and Nathan Clifford Grover (1868-1957) of the USGS. Therein an obvious effort was made to include everything that one must know in order to measure, analyze, and record the temporal rate of flow of the nation's streams. Probably due in part to its federal background, the book received wide recognition and went through several editions. Just the contrary was true of *Hydraulics of Rivers, Weirs and Sluices* by David Albert Molitor (1866-1939) which appeared a year later. A native of Detroit and a graduate of Washington University, Molitor had spent three postgraduate years in central Europe. The book was an interpretation rather than a translation of the work of Hofrat Gustav Ritter von Wex, the Austrian director of the Danube River regulation, and the result was an unfamiliar combination of Teutonic and American practice. Probably because of its very strangeness, it appears to have attracted a much smaller following than standard texts of lesser value.

So much water had come to be used for mining purposes that California rivers gradually became clogged with waste material. In 1907 the USGS established temporary laboratory facilities at the University of California to study the movement of such material. The investigation was under the direction of Grove Karl Gilbert (1843-1918)—who had served as geologist with both the Wheeler and the Powell surveys and on the original USGS staff—with the assistance of Edward Charles Murphy, the latter completing the tests in 1909 during Gilbert's illness and preparing a preliminary report. The final report, written wholly by Gilbert, was published in 1914 under the title *The Transportation of Débris by Running Water*. Its contents have probably received more attention than those of any other work on sediment movement. Three flumes were used in the experiments, varying in length from 14 to 150 feet and in width from 0.2 to 2 feet, the shortest having a glass window for observation. The sediment consisted of sand and gravel screened to 8 grades that varied from 0.3 to 7 millimeters in mean diameter. Water discharges somewhat great than 1.1 cubic feet per second were available. In each run the rates of discharge and of sediment input at the upstream end were fixed, and the flow was then allowed to continue till the rate of sediment output at the downstream end equaled the rate of input; thereupon conditions of equilibrium were assumed, the slope and depth were measured, and a new run was begun. Literally thousands of data were thus accumulated, and it is these—carefully tabulated in the report—which continue to be used by researchers in many parts of the world. Gilbert also sought to formulate relationships between the measured values, but the formulations have received less credence than the values themselves. On the other hand, he introduced many concepts and observations that persist in the literature—for example, the sliding-rolling-saltation-suspension sequence, and the level-bed transition between dune and "antidune" movement.

A 1915 ASME paper that was eventually to have a profound though vicarious effect on American writing and research was "Model Experiments and the Forms of Empirical Equations" by Edgar Buckingham (1867-1940), a physicist with the Bureau of Standards. As he indicated at the outset,

> There is nothing essentially new in what I have to present, but the subject seems to be rather unfamiliar to engineers in general and is worth discussing because of its frequent practical value.

Despite this disclaimer, he made no reference whatever to the four men—Fourier, Vaschy, Riabouchinsky, and Rayleigh—who laid the foundation of the principle he so successfully popularized, and as a result what he named the Π-theorem is invariably referred to as Buckingham's. The paper itself contains the following parts: the general theorem, pipe flow, drag at moderate speeds, projectiles, propellers, and heat transmission, each except the first representing a flow involving the density and one other fluid property and serving as an illustration of what is now called dimensional analysis. Under the subject of pipe flow he copied the new Blasius diagram, giving credit to Saph, Schoder, and the Englishman Stanton for the data but not to Blasius for the original analysis. In other cases he likewise credited the experimenters but not the analysts. Nevertheless, it must be granted that his explanation of the material was most effective, as witness the following significant excerpt from his conclusion:

> The method is not a theoretical one in the ordinary sense—there is nothing hypothetical about it. It is purely algebraic and tells us with certainty, that if certain quantities and no others are connected by a physical relation, the equation which describes the relation must be reducible to a certain form: the only chance of mistake is in overlooking some essential factor in the problem. Since the process of reasoning is purely mathematical, we cannot, of course, get out at the end any more than we put in at the

beginning when we use physical common-sense and experience to write down the original list of variables for the problem in hand. But we get out what we put in in a form which often makes it much more available than when it went in.

A group of textbook writers who published in the second decade of the century might well be treated together, for their works surely bore considerable similarity. The first of these was George Edmond Russell (1877-1953), who was born in Boston and studied at MIT, did graduate work while an instructor at Cornell, and in 1905 joined the staff at MIT (like Cornell, a land-grant institution) and remained there long past retirement; his 1909 *Text-Book on Hydraulics* went through many editions, more for its simplicity and school of origin than for its originality. Hector James Hughes (1871-1930) was an assistant professor at Harvard and Arthur Truman Safford (1867-1951) was a consulting engineer of Boston and part-time lecturer at Harvard when they published jointly *A Treatise on Hydraulics* in 1911; while the book followed the pattern by then so well established, it also showed originality and perception, employing good flow diagrams, logarithmic plotting, and a close tie between theory (including the Bernoulli equation) and practice. The next book was by Stephen Elmer Slocum (1875-1960) of Schenectady, Union College, and (for the still-rare doctorate) Clark University; he taught at the University of Cincinnati, where he wrote on materials, mechanics, noise and vibration, as well as the 1915 *Elements of Hydraulics;* the excellence of the latter in the field of hydraulic machinery (with emphasis on the now-familiar sequence of blade forms and the basic similarity of pumps and turbines) was consistent with his winning of a gold medal for research on marine propulsion. Robert Long Daugherty (1885-. . . .) of Indianapolis differed from the others in being a mechanical rather than a civil engineer; he studied at Stanford, taught there and at Cornell and Rensselaer, where he published the first of many editions of his *Hydraulics* in 1916, and then in 1919 became head of mechanical engineering at Throop College of Technology at Pasadena, which was later to become the California Institute of Technology; there he continued to consult and write extensively on hydraulic machinery. The last of this group of writers was Horace Williams King (1874-1951), like his namesake Williams a Michigander by birth and education, who traveled widely as an engineer (in Nicaragua, China, the Philippines, and the States) before becoming professor of hydraulic engineering at Michigan in 1912; continuing as a part-time consultant (and inventor), he was the author in 1918 of the immensely popular *Handbook of Hydraulics,* a contributor to several other handbooks, and in 1922 coauthor, with Chester Owen Wisler (1881-1961), of the elementary textbook *Hydraulics.*

A notable hydraulic engineer of the New England tradition was Karl

Raymond Kennison (1885-. . . .), born in Canada of American parents and still alive at the time of writing. He studied at Colby College and MIT, taught awhile at Colby (which later gave him an honorary doctorate), worked in the Providence office of John R. Freeman for several years, and then opened his own office in Boston. For the next 32 years he served as consultant to Boston and many other municipalities on problems of water supply and sewerage, and then in 1952 became chief engineer of New York City's Board of Water Supply. The BSCE elected him to both its presidency and honorary membership. Aside from his invention of the Kennison Nozzle for the measurement of sewage flow. Kennison's pertinence to the present discussion lay in his ASCE paper of 1916, "The Hydraulic Jump in Open-Channel Flow at High Velocity." Therein he presumed that the jump should be analyzed in terms of the alternate depths of the energy principle, and it was probably characteristic of the times that only one of the dozen discussers of the paper took exception; that one quoted the Englishman, W. C. Unwin, on the proper use of the momentum principle and cited the experiments of Unwin's compatriot, A. H. Gibson, for verification. It is to Kennison's distinct credit that in his closure he not only acknowledged his error but then plotted Unwin's theory and Gibson's measurements for the first time nondimensionally in terms of the depth ratio d_2/d_1 versus $v_1/\sqrt{gd_1}$ a parameter which eventually became known (in reciprocal form) as the Froude number!

In March 1913, storms of high intensity caused the Miami, Stillwater, and Mad Rivers in southwest Ohio to flood Dayton and neighboring towns to such an extent that over 300 lives were lost and property damage amounting to $100,000,000 was done. In the effort to make a repetition of the disaster impossible, and in the face of considerable opposition from upstream residents, the Miami Conservancy District was formed, and a system of flood-detention reservoirs and river improvements was decided upon. The Morgan Engineering Company was engaged for the detailed planning. The head of the company, Arthur Ernest Morgan (1878-1975), and two of the consultants retained by the company at Morgan's recommendation, Daniel Webster Mead (1862-1948) and Sherman Melville Woodward (1871-1953), were noteworthy in their own right, and at least one of them will be mentioned again at a later point. Morgan, a native of Ohio, had only a high-school education, but he was to acquire many an honorary doctorate for his three fields of accomplishment: he and his company carried some 75 water-control projects to completion; he served from 1920 to 1936 as the very innovative president of Antioch College; and in 1933 he began a five-year chairmanship of the new Tennessee Valley Authority, during which the underlying plans and policy of the organization were established. Mead, of New York State and Cornell

University, was professor of hydraulic and sanitary engineering at the University of Wisconsin from 1904 to 1932 on a half-time basis, conducting a vast consulting practice that continued well after his retirement from the university; he was elected both president and honorary member of the ASCE and received its Norman Medal. Woodward, a native of Minneapolis and a graduate of Washington and Harvard Universities, was professor of mechanics and hydraulics at the State University of Iowa from 1908 to 1934, taking a leave of absence to become consultant to the Morgan Company (and then finally resigning from Iowa to follow Morgan to the TVA).

Not only did Woodward eventually become the staff member of the company in charge of hydraulics, but he was responsible for attracting and supervising the work of a number of excellent hydraulicians. The most notable of these was Emory Wilson Lane (1891-1963), a Hoosier who had studied at Purdue and Cornell and then seen considerable experience both in the States and in China with the Morgan Engineering Company and various federal bureaus; it is interesting to remark that Lane followed Woodward belatedly to Iowa in 1935 and then temporarily to the TVA in 1942. Another hydraulician of note was Ivan Edgar Houk (1888-1972), an Iowan by both birth and education; he joined the Morgan team shortly after graduation from the university, stayed several years beyond the Miami project in Dayton as city engineer, and later became an engineer with the U.S. Bureau of Reclamation at Denver. Ross Milton Riegel (1881-1966) was a Pennsylvanian and a graduate of Cornell, held a variety of hydraulic-engineering posts before and after Miami, and ultimately became chief design engineer with the TVA. John Cleaveland Beebe (1886-1954) of Massachusetts, Dartmouth College, and the University of Wisconsin, was a construction engineer of varied experience.

Morgan, Woodward, Lane, Houk, Riegel, and Beebe were responsible for most of the ten reports finally published by the Miami Conservancy District. These had the following titles:

I The Miami Valley and the 1913 Flood (Morgan)
II History of the Miami Flood Control Project
III Theory of the Hydraulic Jump and Backwater Curves (Woodward)
The Hydraulic Jump as a Means of Dissipating Energy (Riegel, Beebe)
IV Calculation of flow in Open Channels (Houk)
V Storm Rainfall of Eastern United States (Staff)
VI Contract Forms and Specifications
VII Hydraulics of the Miami Flood Control Project (Woodward)
VIII Rainfall and Runoff in the Miami Valley (Houk)

IX Accounting and Cost Keeping
X Construction Plant

The 118-page section on the hydraulic jump is often cited as the definitive work on the subject; although the theory of the phenomenon had actually been established in Italy and France in the previous century, it must be granted that this article did indeed popularize its use through the emphasis of the second part on the practical aspects of jump stabilization investigated at reduced scale. Houk's 283-page treatment of open-channel resistance was a thoroughgoing review of the field, with particular attention to the values of the Kutter coefficient for the Miami Valley. From records of storms in eastern United States and elsewhere, it was estimated by the staff that a flood 15-20% greater than that of 1913 could well occur within a few centuries, and one perhaps 25% greater in 1000 years; the design figure of 40% was thus considered to represent a wholly adequate factor of safety. Woodward's 343-page section on hydraulics involved primarily the balancing of costs of the various improvements under consideration in such a manner as to yield the desired protection with minimum expense—a forerunner of modern systems design; initially a combination of trial and intuition, this procedure was eventually replaced by a direct graphical method since attributed to Lane. Houk's 234-page hydrologic study was ahead of its time in that it foresaw as-yet-unpublished teachings of Horton and Mead to the effect that runoff was not a particular fraction of rainfall but a residual quantity depending not only on the rainfall but also on the infiltration rate, soil-moisture capacity, ground cover, and so on; moreover, he conducted small- and large-scale field experiments which both verified his contention and provided significant local magnitudes of the various parameters. The reports have since been used as textbooks in more than one class.

Establishment of a hydraulics laboratory at the State University of Iowa was somewhat reminiscent of that at Worcester. In 1903 the water rights to a gristmill dating from 1844, located on the Iowa River well upstream from the campus, were deeded to Iowa's School of Applied Science, which later became the College of Engineering. A grant from the Legislature in 1904 permitted construction of a new dam just downstream from the campus, and an opening was left for a 10-foot gate at the west abutment. Before 1906 a small instructional laboratory had existed in the basement of one of the earlier buildings, and in 1914 the newly created Department of Mechanics and Hydraulics undertook the design of a retaining wall next to the dam, a 10x10x130-foot channel, and a 22x22-foot laboratory structure at its downstream end. In the absence at Dayton of Sherman Woodward, who was to head the new department, the project was in the charge of John Hoffman Dunlap (1882-1924), a New Hampshire graduate of Dartmouth College and its

Thayer School of Civil Engineering, who came to Iowa in 1919 and left in 1922 to become Secretary of the ASCE. With Woodward's return in 1920, a young holder of the Michigan doctorate, Floyd August Nagler (1892-1933), was employed to take charge of the new laboratory. Nagler (which he pronounced Nahgler)—like his postgraduate advisors Williams and King—was a native of Michigan, but he had attended Michigan State College before the University. In his first year at the latter institution he performed tests on bridge piers in a temporary experimental facility at the Argo Spillway in Ann Arbor, receiving the Collingwood Prize of the ASCE for his 1918 paper on the results. The following year a paper on the correlation between weir measurements and Groat's salt-dilution method (presumably his doctoral dissertation) received another Collingwood Prize, and Nagler then spent several years in the consulting office of Robert Horton at Vorheesville, New York, not to mention an interval as wartime meteorologist in the Army Signal Corps.

On arriving at Iowa in 1920, Nagler continued his bridge-pier tests in the new 10-foot channel. Two years later, the Department of Agriculture in the meantime having stationed David Leroy Yarnell (1886-1937) of Iowa at the laboratory, the two collaborated with Woodward on full-scale culvert tests, also in the channel. The year 1925 saw the channel used for a model of three sections of the Keokuk Spillway. A comparison of these discharge measurements with current-meter measurements on the prototype structure, published in 1930 by Nagler and Albion Davis (1891-1963) of Keokuk, won the authors the Norman Medal of the ASCE, and a year later Nagler and Yarnell received the Croes Medal for their paper on the effect of turbulence on current-meter registration. By 1928, as a result of Nagler's tremendous drive, the north wing of the present laboratory structure had been built, and the following year the Corps of Engineers established a suboffice for hydraulic-model studies in the new building under Martin Emil Nelson (1898-. . . .) of Wisconsin, the University of Minnesota, and the Royal Institute of Technology at Stockholm. Experiments conducted in 1929-30 on a model of the Hastings Lock and Dam on the Mississippi River in Minnesota represented the first such tests undertaken by the Corps. In 1931 the Iowa Institute of Hydraulic Research was formed to handle the contract projects that were beginning to materialize. The year thereafter the present south wing and central tower were added, again thanks to Nagler, and offices of both the Weather Bureau and the Geological Survey were located in the new structure. This initial era of productivity was brought to an abrupt end by Nagler's untimely death in 1933 from a ruptured appendix which he sought to ignore.

With the moving of the Massachusetts Institute of Technology across the Charles River from Boston to Cambridge in 1916, its new facilities involved not only buildings but also laboratory equipment. George Russell, then an associate professor, described the new hydraulic laboratory in a 1918 article for the *Journal* of the BSCE. It was located with the steam and air-pressure laboratories on three floors of the mechanical-engineering wing. A large basement channel of rectangular plan served as reservoir, from which a variety of pumps delivered Charles River water to channels, measuring tanks, pipes, turbine standpipes, rams, weirs, orifices, and flow meters. Planned for student training in calibration and performance measurements, the equipment was impressively large and inflexible. Ironically enough, one of the flumes had to serve during the summer of 1919 for special tests conducted by Clemens Herschel on a new form of weir. As described in the *Transactions* of the ASME for 1920, the weir consisted of 1-on-2 upstream and downstream slopes, the crest angle studied by Bazin and others being replaced with a rounded section formed by a brass pipe (with a diameter of 4½ inches for weir heights of 3½ and 7 feet). The head was measured between piezometers in the approach channel and in the crest, and it was found during the final tests that locating the crest piezometer at the beginning of the curve (i.e. at its point of tangency with the sloping upstream face) made the rate of flow—at least over the range tested—simply a linear function of the head. Despite Herschel's rather charming description of the study, the weir is not known to have had further users.

Several writers of the early 20th century still remain to be noted. The first of these was William Frederick Durand (1859-1958); a native of Connecticut, he was educated at the U. S. Naval Academy, served as professor at Michigan State, Cornell, and Stanford, and during his long and active life ranged in professional interest through civil, mechanical, marine, and finally aeronautical engineering (he chaired the NACA, forerunner of NASA, as well as countless other professional committees). Among the two-hundred-odd publications listed at the end of his autobiography, the 1921 book, *Hydraulics of Pipe Lines,* was outstanding in comparison with the many of similar title by other writers that merely tabulated resistance coefficients, for its six chapters capably discussed the following items: major and minor losses; surges; water-hammer; stresses; materials, construction, design; and the hydraulics of oil lines. An appendix even presented the still-unorthodox f-vs-R diagram, but with credit to Buckingham rather than Blasius. The next writer was Joseph Nisbet LeConte (1870-1950), a native Californian who obtained his education at both California and Cornell and then became a professor of mechanical engineering at his initial alma mater, where his father and his uncle had already made the family name well-known. Entitled simply *Hydraulics,* his 1926 book emphasized the analysis of the so-called "perfect liquid"; it contained few tables of coefficients, the flow patterns were intelligently drawn, and about one-third of the text dealt with hydraulic machinery. The third writer was Francis Murray Dawson (1889-1963), who was born and educated in Nova Scotia; while a graduate student and (after war service) an assistant professor at Cornell, he aided Professor Schoder with a number of projects, particularly that on weirs, and—so Dawson later claimed—for want of other means of showing his gratitude, Schoder invited him to be coauthor of his very practical 1927 textbook *Hydraulics,* which was to go through a number of editions. Dawson next served as professor at the Universities of Kansas and Wisconsin, and in 1936 he became dean of engineering at Iowa and director of the Iowa Institute of Hydraulic Research, with Lane at a somewhat later date as associate director in charge of the laboratory.

Though they were not textbook writers, mention must be made at this point of three irrigation engineers with the Department of Agriculture who, like David Yarnell, published many bulletins dealing with the practical aspects of flowing water. They were Samuel Fortier (1855-1933), who had migrated to the States from Canada, and Fred Charles Scobey (1880-1962), a Hoosier who had studied at Stanford, both of whom spent most of their professional lives in the western part of the country; and Charles Ernest Ramser (1885-1962) of Iowa and the University of Illinois, who ranged from the East to the Midwest. In 1901 Fortier published a report on the carrying capacities of canals, and in 1902 one on the measurement of irrigation water. Scobey, in turn, published a series of bulletins on the flow of water: in wood-stave pipe, 1916; concrete pipe, 1920; riveted and similar pipe, 1930; flumes, 1933; and canals, 1939. Ramser, an early proponent of terracing farmlands, wrote a series of bulletins on conservation measures, as well as the much-used 1929 Bulletin 129 on drainage canals, which illustrated photographically various values of the Manning *n*. In 1926 Fortier and Scobey together were authors of an ASCE paper on permissible canal velocities. Therein a distinction was made between conditions necessary to transport sediment and to scour the bed, and the latter were found to depend on the grading of the bed material, the presence of colloidal matter, and the age of the bed; vegetation was shown to be of no importance, since it could not grow under conditions of maximum permissible velocity.

Readers may well have noticed that most of the hydraulicians who have been cited in these pages were civil rather than mechanical engineers. This has been due in large measure to the fact that civil-engineering hydraulics dealt primarily with public works and mechanical-engineering hydraulics with private commercial ventures. The various pump and turbine companies usually operated their own test laboratories, and the turbine manufacturers in particular jealously guarded their industrial secrets. A primary exception was Forrest Nagler (1885-1952)—a cousin of Floyd who pronounced the name Naygler—also a Michigander by birth and education, who spent most of his professional life with the Allis-Chalmers Manufacturing Company developing improved turbine runners; an early axial-flow turbine was his invention, as well as a novel cross-flow variant of the Pelton wheel. On the other hand, dating from the time of Storrow and Francis, the measurement of discharge rate had played an important part in the hydraulic-machinery profession, and within the Hydraulic Division of the ASME there came to exist a group comprising Allen, Gibson, and various others of similar interests who were later to call themselves "The Hydraulic Old-Timers." One of these was Edward Smith Cole (1871-1950), another Cornell alumnus, who in 1896 developed the so-called Pitometer, an instrument with short tubes pointing both upstream and downstream, each of which could be rotated through nearly 180° to permit insertion of the instrument through a valve in a penstock wall; for this he received the ASME Warner Medal. Also a prominent member of the group was Lewis Ferry Moody (1880-1953), a Philadelphian and graduate of the University of Pennsylvania, who served as consultant to both pump and turbine companies and as professor at Pennsylvania, Rensselaer, and finally Princeton; an early authority on such matters as similitude and specific speed, he is credited with a number of inventions in the field of hydraulic machinery, including the first propeller turbine with adjustable blades and the spreading draft tube that bears his name, and he should be credited as well with formulating the cavitation parameter that bears Thoma's name. Before leaving the subject of draft tubes, note should also be taken of the "hydraucone regainer" invented by William Monroe White (1871-1949) of Alabama and Allis-Chalmers; both Moody's and White's tubes were axisymmetric to avoid the loss inherent to the elbow type; paradoxically, however, the cone was essential to Moody's continuous increase in flow area, but not to White's principle of deflection; the discussion by Moody and others of White's 1921 paper is significant. Pertinent to methods of measurement though not to the ASME group of Old Timers was a 1928 ASCE *Proceedings* paper by an Italian professor, Angelo Barbagelata, who combined the essentials of Groat's salt-titration method and Allen's salt-velocity method to yield the electrical-conductivity method. Based on the nearly linear relation between the concentration and the electrical conductivity of a salt solution, the degree of dilution of a concentrated additive was determined by integrating a conductivity-time graph recorded some distance downstream; Barbagelata thus avoided Groat's time-consuming titration process and Allen's complex injection system. Unfortunately, the method remained far more foreign to American practice than its special features merited—in fact, the paper was never even upgraded from *Proceedings* to *Transactions.*

Less than forty years after the establishment of a hydraulics laboratory at the University of California, a full thirty-eight other educational institutions claimed to have experimental facilities worthy of recognition by the Engineering Foundation. These were listed and briefly described in 1922 in a special publication of the Foundation, *A Descriptive Directory of Hydraulic Laboratories in U.S.A.* In addition to the educational facilities, ten other establishments were included, only two of which (the Department of Agriculture laboratory at Fort Collins and the Bureau of Standards' rating tank at Washington) were federal. On reading the descriptive material provided by each institution, one cannot escape the conclusion that by far the majority existed for the purpose of giving students practice in the use of measuring instruments or, in the case of the private companies, to permit the testing and further development of machines. Under the heading "research" the implication of the word was usually missed and—except for the few institutions already discussed in the foregoing pages—an effort was simply made to indicate activity of one or another ambiguous nature.

In view of the subject matter of the following chapter, it seems relevant to look as well into the quality of the model studies that had been conducted thus far. Franklin's tiny canal and towboat were surely precursors of the huge installations to follow, but they could hardly be considered scale models of prototype structures. Freeman and Williams modeled the old Croton Dam profile at reduced scale, but their similarity criterion was purely geometric, and the discharge coefficient was tacitly assumed to be the same at all scales. Small-scale studies of the stilling basin below the Morgantown Dam by Riegel and Beebe were also on a purely geometric basis, hydraulic jumps of the same depth ratio being presumed similar at all scales; reference was made in their report to Kennison's paper—but not to his unwitting use of the Froude number in his closure. Nagler and Davis advanced beyond Freeman and Williams' two-dimensional study by modeling three bays of the Keokuk Spillway with pier effects, and they also sought to simulate the surface roughness by various applications of shellac and sand; however, their similitude parameter was still the discharge coefficient. Martin Nelson's tests on the Hastings Dam model differed little from those long since under way in European laboratories, and they were probably influenced by the returning visitors discussed in the next chapter. Who built the first American model is actually less important than the fact that continued progress was being made. It is nonetheless significant that the simplified principles of similarity in use by 1930 definitely stemmed from continental hydraulic practice rather than from the more refined analysis that Buckingham had sought to publicize in this country fifteen years before.

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CHAPTER V

JOHN R. FREEMAN'S INFLUENCE

During the course of extensive travels mentioned toward the end of Chapter III, Freeman became acquainted in 1913 with Professor Hubert Engels of the *Technische Hochschule* at Dresden, Germany, and was deeply impressed by his laboratory for the study of river hydraulics through use of small-scale models. No doubt it was the potential worth of the principle rather than the smallness of the scale that attracted him, for he clearly had reservations about the latter. It is of particular interest that in the following years during the planning of the new "Boston Tech" across the Charles River in Cambridge, Freeman prepared drawings for a large river-hydraulics laboratory (and for other buildings as well), the very size of which finally caused it to be "crowded off the campus." But Freeman did not easily give up. In 1919 he employed Hardy Cross (of subsequent moment-distribution fame) to prepare a 1000-page review of literature on river hydraulics prior to a consulting trip that he (Freeman) was to make to the Yellow River in China. He further propagandized among professional groups at home, in California, and even in China, at first in favor of merely a river laboratory but eventually of a national laboratory for other hydraulic purposes as well. The gist of such a talk before the Washington Society of Engineers was communicated to Senator Joseph Ransdell of the delta state of Louisiana, who found the idea so worthy that he met with Freeman and then in June 1922 introduced the following bill in the Senate:

SENATE JOINT RESOLUTION 209

To establish a national hydraulic laboratory.

Whereas floods are causing increasing losses along many of the streams of the United States; and

Whereas there is great lack of information on this matter which is of vital concern to the people in various sections of the United States; and

Whereas there is disagreement among the best authorities on fundamental practices involved; and

Whereas systematic research and comprehensive study of flood-control experience and practice in all ages and in all countries promises to be helpful in meeting problems on streams in the United States.

Therefore be it

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That a national

> hydraulic laboratory be established in the District of Columbia, in connection with such bureau as the President may designate, for the conduct of research, experiments, and scientific studies in connection with the problems of river hydraulics, and an appropriation of $200,000 is hereby authorized for that purpose.

By chance this was the same year that Freeman served the ASCE as president, and his address at the annual convention—printed in full in the 1922 *Transactions*—dealt in large part with the foundation of a National Hydraulic Laboratory and the amount of good that it could do, particularly in connection with the regulation of such rivers as the Missouri and the Mississippi. In view of the vast sums of money being spent each year on river navigation and flood control with rather questionable results, he argued that the use of model studies in combination with field experience should yield savings far in excess of the laboratory costs.

Now the Mississippi and the Missouri, not to mention other navigable rivers, had been the primary concern of the Corps of Engineers for roughly a century, and any criticism of its work was not likely to be well taken. In fact, so much money had been spent by the Corps on so many huge projects that, perhaps naturally, it had come to equate expenditure with expertise, as reflected in the following statement of one Chief of Engineers:

> The Science of River Hydraulics in America, both theoretical and practical, as a whole is more advanced than that of any other nation in the world, and this advance is due almost exclusively to the activities of the Army Engineers.

Spurred on, no doubt, by the possibility that the establishment of a laboratory in any other bureau might take at least part of the responsibility for river control out of the Army's hands, it became official policy to oppose such a laboratory on the grounds that a small-scale model could tell the Corps nothing more—and probably far less—than it already knew from its century of experience with the actual rivers. Though very many civilian engineers appeared before Congress in favor of the proposed bill, the sole representative of the Corps to testify, a long-time member of the Mississippi River Commission, carried such weight that the bill was easily defeated.

In the mind of at least one observer, the situation was reminiscent of the Corps' opposition to James Eads' bridge at St. Louis, to Eads' subsequent efforts to improve the Mississippi Delta, to Arthur Morgan's policy of reservoir control of flooding, and finally to Morgan's planning of the Tennessee Valley Authority. As Morgan himself saw it, West Point trains for wartime—not peacetime—engineering activities. Discipline and the chain of command are hence all-important, as is the consistent adherence to a policy once it has been established. Add to this the close cooperation that had developed over the years between the Corps and Congress in the planning, justification, and carrying out of local projects. Morgan hence found little that was surprising in the fact that in the following years the same legislation was twice reintroduced and twice again defeated. In 1927, however, despite the Army's repeated assurances to Congress that its Mississippi levee system was safe against floods, there came the greatest flood in memory, with tremendous loss of life and property. Directed by Congress to make a repetition impossible, the Corps grasped at every means available—except for departure from its standard levee practice. In particular, its official position rapidly shifted to the point that the Chief of Engineers then in office recommended the establishment of a hydraulic laboratory—under the jurisdiction of the Corps! It could well be, as some surmised, that this was simply a protective move without serious intent to implement it, prompted by the fact that the Ransdell bill presented to Congress in 1928 specified the Bureau of Standards as the recommended site. Freeman nevertheless diplomatically wrote the Chief of Engineers as follows:

> My own belief is that the Federal Government could with great profit establish at least two of these laboratories, one at the Bureau of Standards, the other at St. Louis or New Orleans, under the U. S. Army Engineers, adjacent to the Engineering School. I believe that both would soon be occupied with problems and would produce results of great practical value.

In the meantime Freeman had been far from idle. First, in the years 1924, 1925, and 1926 he had endowed three traveling scholarships, one each with the ASCE, the BSCE, and the ASME. Second, he had prevailed upon the *Verein Deutscher Ingenieure* to publish *Die Wasserbaulaboratorien Europas,* a 1926 book describing the river-hydraulic establishments on the continent, with the understanding that he would have it translated and republished in the States. Finally, the year the book appeared, he persuaded MIT to bring to Cambridge one of the book's co-editors, Dr. George de Thierry, Professor of River and Harbor Engineering at Charlottenburg, as the first of a series of lecturers (followed by Theodor Rehbock, Dieter Thoma, Ludwig Prandtl, and—for a two-year period—Wilhelm Spannhake. Freeman's letter of endowment to the BSCE warrants reproduction at this point:

To the President and Directors of the
Boston Society of Civil Engineers
Tremont Temple, Boston, Mass.

Gentlemen:

I owe a debt to the old Boston Society of Civil Engineers, for inspiration and encouragement it gave me in my younger days through friendships and acquaintances made at the Society meetings.

It was forty-four years ago that I joined the Society. Month after month for about four years I felt well repaid by what its monthly meetings had to give, for making a sixty-mile round trip with a return after midnight. Yet today, forty years later, I have a still deeper appreciation of what the Society associations may mean to a young engineer.

I doubt if those grand men—Joseph P. Davis, Alphonse Fteley, Thomas Doane, George L. Vose and many others—realized how much encouragement their presence and friendly words gave to us youngsters. Also there were warm friendships made with members of a wonderfully fine group: Henry Manley, John Cheney, Fred Stearns, Dexter Brackett, Frank Hodgdon and many others, but few of whom now remain except FitzGerald, Carson, Howe, Swain, Hale and myself.

It seems only fair that, when one has found lifelong happiness, and attained a competence from his profession, he should recognize the debt he owes to those who went before him and whose data he used, and should in some way try to help those young men in his profession who are following after.

In grateful recollection of these benefits I would now find pleasure in presenting to the Boston Society of Civil Engineers securities having a present value of approximately $25,000 and a present annual income of about $1,700.

It is my desire that the income be particularly devoted to the encouragement of young engineers in various ways, such, for example, as the following:

(1) By grants towards expenses for experiments, observations, and compilations towards data that will be useful in engineering and are reported to the Society.

(2) For underwriting fully or in part some of the loss that may be sustained in the publication of meritorious books, papers or translations pertaining to hydraulic science and art which might, except for some such assistance, remain mostly inaccessible to the membership of the Society.

(3) Or such portion of the annual income as the Directors deem

proper might be devoted to a yearly prize for the most useful paper relating to hydraulics contributed to this Society during the calendar year, no award being made unless a paper has been presented that is deemed worthy of special recognition, preference being given to the work of students, juniors or members under forty-five years of age.

(4) I suggest that from the income of this fund there be established once in three years a travelling scholarship, open to members under forty-five years of age, in any grade, in recognition of achievement, or promise; and for the purpose in aiding of visiting engineering works in the United States or any other part of the world where there is good prospect of obtaining information useful to engineers, report of what is found interesting to be made to this Society.

Since needs or calls may change from time to time, I suggest that suggestions for grants for special purposes be invited, and a flexible program followed.

I would enjoy serving for a time as one member of a committee of three or five to be appointed for the administration of this "Freeman Fund" until we can find out how to make the most of it.

If found useful, doubtless other members will from time to time add similar funds.

In the history of the Royal Society and that of the American Association for the Advancement of Science I have been impressed with the occasional helpfulness of a small fund to a young investigator full of the zeal of youth but limited in resources for investigation.

For the above purposes I have been getting together some securities, and desiring the largest return for present purposes I have tried to safeguard this by broad distribution in the preferred stocks of twenty-five different corporations serving widely scattered communities. These largely are hydro-electric stocks.

When one or another of these is "called" for retirement, I suggest reinvestment be made along similar lines.

Yours very truly,

John R. Freeman
Member, Boston Society of
Civil Engineers

Six Freeman Scholars were chosen by the three Societies the first year, 1927, largely under Freeman's guidance, plus one MIT Fellow on funds made available by a fortuitous duplication of the lectureship appropriation. Freeman himself spent several weeks with his protégés in Germany visiting the principal laboratories. Several of the group stayed a second year and were joined by two more from the Societies and one—Lieutenant Herbert Davis Vogel (1900-. . . .) of Michigan and West Point—who was assigned to Europe for that year by the Corps of Engineers. This actually made two representatives of the Army to study model techniques in the first two years, for Blake Van Leer of the initial delegation was a reserve member of the Corps. As may be seen from the accompanying list of fund recipients (members of the Corps being indicated by asterisks), the benefits resulting from Freeman's endowments have continued to the present day, despite reduction in the relative value of the endowment funds, and many of those listed will again be mentioned in subsequent pages. A number of them (as well as a dozen others among Freeman's associates) contributed to translation of the German book on laboratories, and the promised American version, *Hydraulic Laboratory Practice,* appeared in 1929 under the ASME imprint. What with additional material assembled by Freeman and his associates, the 868-page tome was more than twice the size of its precursor.

In the meantime, the laboratory proposal had continued to meet with at least partial failure. In 1928 Congress defeated Senator Ransdell's bill to establish the National Hydraulic Laboratory at the Bureau of Standards, again as a result of the Corps' opposition, yet the same Congress paradoxically approved the establishment of a laboratory by the Corps. After some debate as to the proper location, Vicksburg—headquarters of the Mississippi River Commission—was chosen, and the establishment was placed under the jurisdiction of the Commission and named the Waterways Experiment Station to avoid any implication of either laboratory or hydraulics. On his return from Europe with the German doctorate in 1929, Lieutenant Vogel became the first director, and planning began.

Because of the Corps' customary adherence to policy, its opposition to the Bureau of Standards laboratory would probably have continued indefinitely had not President Hoover (who was familiar with the situation from his term as Secretary of Commerce) utilized his power of appointment to change the policy. In 1930 he deliberately passed over ten officers recommended for his consideration as the new Chief of Engineers till he found one—Major General Lytle Brown (1872-1951)—on whose unbiased judgment he could depend. When General Brown testified before the House Committee in early 1930, his opening statement was to the following effect:

> Mr. Chairman and members of the committee, I am of the opinion that there is a need for a national hydraulic laboratory, as indicated in the bills introduced, I believe, by Senator Ransdell and Representative O'Connor.

FREEMAN SCHOLARSHIP AWARDS

Boston Society of Civil Engineers

1927-29	Kenneth C. Reynolds	1937-38	Martin A. Mason
1928-30	Samuel Shulits	1948-49	Ralph S. Archibald
1930-32	Clifford P. Kittredge	1949-50	Carroll T. Newton
1932-33	Lawrence DeFabritis	1954-55	Lawrence C. Neale
1934-36	Leslie J. Hooper	1958-59	Robert G. Dean
		1963-64	Edward R. Holley Jr

The BSCE Freeman Fund was used in 1966 to establish an annual John R. Freeman Memorial Lecture. This has been presented in turn by Hunter Rouse, Hans Gerber, John Parmakian, Thomas Camp, Klas Cederwall, Arthur Ippen, Ven Te Chow, Harry Headland, and Donald Harleman. In 1975 the BSCE, by then a Section of the ASCE, announced an annual Freeman Hydraulics Prize for a comprehensive work in the field of hydraulic engineering; the first such award went that November to Hunter Rouse for a preliminary version of the present treatise.

American Society of Civil Engineers

1927-28	F. Theodore Mavis	1932-33	Herbert H. Wheaton
	Morrough P. O'Brien	1935-36	* Paul W. Thompson
	Lorenz G. Straub	1936-37	John Hedberg
1928-29	Clarence E. Bardsley	1938-39	Douglas C. Davis
1929-30	James G. Woodburn	1939-40	* Miles M. Dawson
1930-32	* Hans Kramer	1940-41	* Haywood G. Dewey Jr
1932-33	Donald P. Barnes	1947-48	* George F. Dixon

ASCE and ASME began alternating in 1951, the former taking the odd years.

1953-54	* Ira A. Hunt Jr	1965-66	Hsieh W. Shen
1955-56	Walter J. Tudor	1967-68	Frederick A. Locher
1957-58	Norbert L. Ackermann	1969-70	F. G. Alden Burrows
1959-60	Willard E. Fraize	1971-72	V. W. Goldschmidt
1961-62	Jacques W. Delleur	1973-74	Walter Hans Graf
1963-64	Roger J. M. De Wiest	1975-76	Wilfried H. Brutsaert

American Society of Mechanical Engineers

1927-28	Herbert N. Eaton	1935-37	Victor L. Streeter
	Blake R. Van Leer	1946-47	T. H. Chien
1929-30	Robert T. Knapp		J. C. Ma
1931-32	R. Whitaker	1954-55	Alexander Rudavsky
1932-33	G. Ross Lord	1966-67	James F. Wilson
1933-34	* Hugh J. Casey	1968-69	James P. Johnson
		1970-71	C. S. Martin

In the early years the ASME Freeman Fund was frequently used to support the publication of books—for example, *Hydraulic Laboratory Practice* and *Experiments on the Flow of Water in Pipes and Pipe Fittings.* Beginning in 1971 grants were made in the form of honoraria for reviews of progress in various phases of fluids engineering; the recipients to date have been J. W. Hoyt, R. F. Probstein, J. E. Cermak, and W. J. McCroskey.

M.I.T. TRAVELING FELLOWS IN HYDRAULICS

1927-29	John B. Drisko	1929-31	Hunter Rouse
		1931-32	Cedric H. MacDougall

The committee was dumbfounded and questioned the General very critically indeed. He later sought to clarify the apparent about-face of the Corps—by a letter which included the statement:

> I am informed by a creditable witness that opposition to the laboratory formerly on the part of some engineer officers was through an impression that the laboratory might be used by irresponsible parties to dictate to the Corps of Engineers as to how work entrusted to its care should be executed, and so be constituted as an origin of controversy, delay and confusion. I see no foundation for that view and have not the least fear of any such evil.

With General Brown's support there was no further reason for delaying passage of the bill. On May 14, 1930, President Hoover finally signed "An Act authorizing the Establishment of a National Hydraulic Laboratory in the Bureau of Standards of the Department of Commerce and the Construction of a Building Therefor." (It might be noted nonetheless that the Act contained a clause prohibiting the laboratory from doing work in the field of any other agency without request from that agency!)

Even before the bill was passed, Freeman and his staff had prepared extensive designs for the building and its major equipment. While much free space was foreseen, the pumping and circulation system was very large, to the end of permitting the calibration, once and for all, of full-scale measuring devices reminiscent of his Lowell days. It was Freeman's intention to build according to what he felt were the needs (rather than in keeping with the funds available) and then going to Congress for additional support, whereas the Bureau administration insisted on remaining within the appropriation for the costs of both building and equipment. The rift resulting from this difference in policy gradually widened, and at last Freeman withdrew from active participation. The final laboratory structure still reflected many of the strengths as well as weaknesses of Freeman's designs; although the system was relatively inflexible, and some of the largest units were never to be used, still a great deal could have been accomplished therewith. Herbert Nelson Eaton (1892-1970), a native of Massachusetts with degrees from Worcester and Johns Hopkins and one of the original Freeman Scholars, became the first director; as such, he gradually assembled a small staff, including Karl Hilding Beij (1893-. . . .), who was born and educated in Connecticut, and Garbis Hvannes Keulegan (1890-. . . .), an Armenian immigrant who earned degrees in physics from Ohio State and Johns Hopkins, but only one other Freeman scholar, Lawrence Lamont DeFabritis (1908-1943) of Connecticut and MIT. Martin Alexander Mason (1907-. . . .) of Washington DC, who became a Freeman Scholar after six years on the staff, returned for several years and then joined the Corps' Beach Erosion Board. Perhaps the most noteworthy of the institution's accomplishments was the publication beginning in 1933 of an annual summary of activities of other hydraulics laboratories in the United States discussed later in this chapter. Why the Bureau of Standards laboratory never prospered was probably a matter of leadership in its various aspects. Once Freeman had withdrawn, there was no person or organization to provide the necessary stimulation and guidance, and the whole project—hope for which had once been so great—gradually withered on the vine.

The paradoxical part of the situation lies in the fact that the laboratory of the Corps of Engineers was the one to thrive despite the perennial conviction reflected in the statement of a former chief:

> . . . it should be clear that the forces of nature let loose in a flood in one of our great rivers cannot be reproduced in a laboratory. I may go so far as to say that I would regret it as a mis-application of government funds to establish such a laboratory for the study of flood problems.

Not only floods but essentially every other aspect of river hydraulics came to be reproduced in the Waterways Experiment Station as it grew from an initially open experimental area of 147 acres to a well-utilized property over four times that size. The summer of 1930 Freeman Scholar Clarence Edward Bardsley (1894-1967) of St. Louis, who had been educated at Missouri and Michigan, worked there on a small backwater model, and—because few staff members could be spared from other districts of the Corps—university students were also employed on a temporary basis. The director gradually added to his permanent staff such young men as Frederick Raymond Brown (1912-. . . .), born and educated in Illinois; Joseph Morton Caldwell (1911-. . . .), George Bradford Fenwick (1906-. . . .), and John Joseph Franco (1908-. . . .), all of whom were born and educated in Mississippi; Eugene Palmer Fortson (1906-. . . .) of Georgia, with a degree from Texas A & M; Robert Young Hudson (1912-. . . .), a native of Tennessee with degrees from Tennessee and Iowa; and Joseph Benjamin Tiffany Jr (1909-. . . .), a Missourian with an Illinois degree. These men gradually developed sound experimental procedures, and all continued to serve in positions of responsibility until their retirement. Details of their activities and those of later appointees will be discussed in subsequent chapters. Eventually additional laboratories of the Corps were developed on a smaller scale in other parts of the country—the first of which, that already mentioned at the University of Iowa, actually having begun experimentation a full year before the WES. Perhaps the gravest fault that can be found with the work of these laboratories is a reflection of the statement made about the Corps members by a Secretary of War early in the century:

> Their powers and duties are fixed by Congress. They are prohibited by Congress from making original investigations or recommending projects.

At this point a brief review of the careers of the Freeman Scholars of the first few years, in groups as tabulated, will give some idea of the range of effectiveness of the selection process. First of the BSCE appointees, Kenneth Cass Reynolds (1897-. . . .), a native of the Boston area, received his professional education at MIT, where he returned after his years in Europe to develop a small river-hydraulics laboratory and continue his pursuit of the doctorate; the three MIT Fellows joined the laboratory staff in sequence as they completed their years abroad—the first, John Bucknam Drisko (1906-. . . .), also of the Boston area, returning via Siberia and Japan—but the last two were dropped in 1933 because of the Depression; thereafter Reynolds constructed a tidal model of the Cape Cod Canal, the most noteworthy feature of which was the electronic control and registration of the continuously changing water levels (an original development by Harold L. Hazen of the MIT EE Department). In 1932 Drisko translated Wilhelm Spannhake's *Kreiselrader als Pumpen und Turbinen (Centrifugal Pumps, Turbines and Propellers)* while the author was at MIT. Samuel Shulits (1902-1973), also a native of Massachusetts and a graduate of MIT, was commissioned by Freeman to translate (on Shulits' recommendation) Armin Schoklitsch's *Der Wasserbau (Hydraulic Structures)* while stationed in the author's city of Brunn, Czechoslovakia; however, the work dragged over several years and had to be completed by another Scholar; Shulits thereafter served with the Corps, the Bureau of Reclamation, and several universities. Clifford Proctor Kittredge (1906-. . . .), likewise from Massachusetts and MIT, spent two years with Thoma at Munich in work toward the doctorate; it was he who finally prepared Freeman's pipe-flow data for publication, after which he taught at Illinois and Princeton.

Of the three initial members of the ASCE Scholars, Frederic Theodore Mavis (1901-. . . .), a native of Arkansas and holder of the Illinois doctorate, returned from Danzig, Karlsruhe, and Berlin to the University of Iowa, where he took charge of the Institute of Hydraulic Research as associate director following Nagler's death; he later relinquished that position to Emory Lane, who had come to Iowa from the Bureau of Reclamation in 1935, in favor of the chairmanship of Mechanics and Hydraulics. Morrough Parker O'Brien (1902-. . . .), a Hoosier and MIT civil-engineering graduate, spent most of his scholarship year at Stockholm and after his return took a position in mechanical engineering at the University of California, Berkeley; Freeman then claimed to have said to him: "Mike, I want you to discuss every hydraulics paper published by the ASCE, so that you will get into the habit of writing"; fulfillment of the great promise that O'Brien showed in hydraulics was eventually confined to the consulting field, for he made his name largely administratively as department chairman and dean of engineering. With O'Brien, Lorenz George Straub (1901-1963) probably satisfied most completely Freeman's hopes for his Scholars; born in Missouri and educated through the doctorate at Illinois, a few years after his return to the States he not only translated Otto Franzius' *Der Verkehrswasserbau (Waterway Engineering)* in its entirety but finished Shulits' translation of Schoklitsch's *Der Wasserbau,* arranged for the publication of both, and at roughly the same time (1936-38) designed and built with WPA assistance the St. Anthony Falls Hydraulic Laboratory at the University of Minnesota. Of the subsequent ASCE appointees, Clarence Bardsley held many different positions after his scholarship travels, including stints with the Bureau as well as the Corps; while at Oklahoma he wrote a short history of hydraulics, much of which (including the naiveté) bore considerable resemblance to pages in Humphreys and Abbot, though these authors were not even mentioned therein. James Gelston Woodburn (1894-. . . .), of Indiana, obtained degrees from Purdue and Michigan prior to his year abroad, and he afterwards advanced through the ranks at Washington State and Wisconsin. Hans Kramer (1894-1957), a West Pointer, profited by his German background and obtained a doctorate under Engels at Dresden; his dissertation was one of two by Americans warranting special mention; unlike many succeeding Freeman Scholars from the Corps, however, his considerable talents were never utilized at Vicksburg.

Of the first two ASME Scholars, Herbert Eaton, who has already been mentioned as the first director of the National Hydraulic Laboratory, came from Massachusetts and was educated at Worcester and Johns Hopkins. The second, Blake Ragsdale Van Leer (1893-1956), was born in a part of Texas that was later transferred to Oklahoma and was educated at Purdue and at California, where he taught hydraulics from 1915 to 1928; his work following the year abroad was largely administrative, including a few years with the American Engineering Council, a deanship at Florida, and the presidency of the Georgia Institute of Technology. In the second year of the ASME series, Robert Talbot Knapp (1899-1957) of Colorado, a holder of a bachelor's degree from MIT and a Caltech doctorate, was another Scholar of whom Freeman would have been particularly proud; upon his return to Pasadena he organized a succession of laboratories (hydraulic machinery, sedimentation, and high-velocity flow) and helped attract to the California Institute a long series of young men who were to play a continuing role in the profession.

Though perhaps only an indirect result of Freeman's endeavors to promote hydraulic laboratory practice, the Thirties saw the establishment of a number of institutions by the federal government. Primary among these was that of the Bureau of Reclamation. Investigations with hydraulic models had their start at the Bureau in August 1930, when a dozen engineers, technicians, and mechanics from Denver commenced work in the hydraulics laboratory of the Agricultural Experiment Station at Fort Collins, which had been built in 1912 under the direction of Ralph Parshall. The work began with a study of proposed shaft spillways for Hoover Dam; as a result of these tests, a change was made from the shaft to the side-channel type. Thereafter many other studies were undertaken, in particular for the Bureau's Grand Coulee and Imperial Dams and for the Tennessee Valley Authority's Wheeler and Norris Dams. Emory Lane was administrative head of the Fort Collins laboratory, which worked two shifts during the Hoover spillway tests under Charles Walter Thomas (1906-. . . .) and James Wesley Ball (1905-. . . .), both Coloradoans educated at Colorado State. Lane later went back to Denver, turning the Fort Collins operation over to Jacob Eugene Warnock (1903-1949), a Hoosier with degrees from Purdue and Colorado. Upon Warnock's move to Denver, Ball was left in charge.

Other Bureau laboratories were established in various places as particular needs arose. During the clement seasons of 1931-36, a laboratory was operated on the South Canal of the Uncompahgre Project near Montrose, Colorado, where a head of 50 feet and a discharge of 200 cubic feet per second were at hand. In addition to Thomas, the staff included Whitney McNair Borland (1905-. . . .), of Colorado and California, who became known for his work in sedimentation. This laboratory was used to test large models of the Hoover side-channel spillways, a complete sedimentation model of Imperial Dam and its appurtenant works, and a model of the dam and spillway bucket for Grand Coulee. For several years during the studies of the spillway for the dam, a 1:60 scale model of the structure was maintained at Grand Coulee.

During the period 1934-37 the Hydraulics Laboratory was maintained in the basement of the Old Post Office in Denver under Lane's direction. Many of the smaller structures designed by the Bureau were studied at that time, whereby a number of young hydraulicians gained laboratory experience. These included John Drisko and Frank Bixby Campbell (1904-. . . .) of Ohio and Cornell, as well as three Freeman Scholars: Donald Porter Barnes (1907-. . . .) of New York, Oregon State, and Caltech; Haywood Guion Dewey Jr (1913-. . . .) of Maryland, Cornell, and Colorado; and Victor Lyle Streeter (1909-. . . .), a Michigander by birth and education. In 1937, when the addition to the New Customhouse was completed, the equipment in the former structure was moved there to establish a small but convenient laboratory. Operation of the Fort Collins facility was discontinued by 1938, after being expanded to about four times its 1935 size to meet the ever-increasing assignments. In 1939 laboratory facilities were installed in the Arizona canyon-wall outlet house at Hoover Dam to use a head of 350 feet and discharge of 200 cubic feet per second available there. While some duplication of effort existed between the Corps and the Bureau, the latter remained primarily interested in the power and irrigation aspects of river development and the former in the navigation and flood-control aspects—plus, of course, estuaries, harbors, and coasts. In most cases the research potential of their work was given little heed.

For many years state and local governments had sought to protect their shores from encroachment by lakes and seas, largely for recreational purposes. Through a committee of the National Research Council, an organization known as the American Shore and Beach Preservation Association came into being in 1926, at much the same time that Freeman was pressing for a national laboratory. Recognizing the need for nationwide coordination, the Association recommended that Congress consider sponsorship by the Corps of Engineers, and in 1930 Public Law 520 gave authority to the chief to conduct investigations toward "devising effective means of preventing erosion of the shores of coastal and lake waters by waves and currents." It is to be noted that the bill provided for studies only, on request, and through the provision of matching funds. A seven-member Beach Erosion Board was set up that year, four members to be officers of the Corps and three to be civilians appointed by the Chief from cooperating agencies. From the outset, the primary civilian member was Thorndike Saville (1892-1969), a native of Massachusetts with degrees from Harvard, Dartmouth, and MIT; at the time of his appointment he was professor of hydraulic and sanitary engineering at the University of North Carolina, but he moved two years thereafter to New York University, where he became dean of engineering in 1935; he remained with the Board for its duration, but also consulted extensively on related problems in various parts of the world. Freeman Scholar Morrough O'Brien was employed the first year of the Board's existence to make a reconnaisance study of beaches, inlets, and harbors along the entire US Pacific Coast; his seven-volume report of 1931 contained much of value, including matters of estuarial tidal prisms, and littoral drift along the sandy shores. When the Chief of Engineers appointed the Beach Erosion Board, it is interesting to remark, he also appointed a Shore Protection Board to deal with coastal navigation. It consisted of the same four officers (without their civilian complement), and utilized the same staff and headquarters at Fort Humphreys (now Fort Belvoir), 30 miles south of Washington. Shortly after its formation, this Board provided $1500 for the construction, by 1932, of a small wave tank 24x12x1½ feet in size. Five years later a larger tank 85x14x4 feet was built at nearby Dalecarlia Reservation, and a civilian staff was gradually developed to conduct tests.

As the Tennessee Valley Authority commenced its first major engineering effort, the chief of the design division, Albert Stevens Fry (1892-1974) of Iowa and the University of Illinois, soon sensed the need for a hydraulics laboratory within the organization. George Harold Hickox (1903-. . . .), a Washingtonian educated at Iowa and California who had been employed several years by Arthur Morgan's engineering company, joined the TVA the end of 1934 and undertook the laboratory development. Test, shop, and office space of some 10,000 square feet was provided at Norris, Tennessee, with an 8x8x120-foot flume and a pumping capacity of 32 cubic feet per second. During the 13 years that Hickox headed the facility, model tests were conducted on all major hydraulic appurtenances of the 16 principal dams built by the TVA to provide flood control, navigation, and power for the drainage basin of the Tennessee River. An early member of the laboratory staff was Alvin Joseph Peterka (1911-. . . .) of Ohio and Case Institute, who later transferred to the Bureau of Reclamation. One of the unique aspects of the experimental work was a program of prototype observation initiated by Fry and Hickox; because of the laboratory proximity to the projects which had been investigated, a salutary check could be maintained on the reliability of the model indications.

At much the same time, the newly organized Soil Conservation Service of the Department of Agriculture established several laboratories for the study of sediment problems and also used the facilities of the Bureau of Standards. The station at Greenville, South Carolina, was manned by Alvin George Anderson (1911-1975), born and educated in Minnesota and eventually to join the staff of the St. Anthony Falls organization; and by Hans Albert Einstein (1904-1973), who had already conducted similar research at the Technical University of Zurich and was thereafter to go to the University of California via Caltech. There was also an SCS field station at Statesville, North Carolina. Joe William Johnson (1908-. . . .), a Kansan educated at California and later to return there to specialize in coastal problems, was active in the SCS Washington office. The SCS laboratory organized at Caltech by Knapp, already mentioned, will—together with his other laboratories—be discussed in detail in the following chapter.

In the 1931 *Transactions* of the AGU, a publication which had been established barely a decade before, there appeared an article

"Formation of the Section of Hydrology of the American Geophysical Union" which began as follows:

> The American Geophysical Union is the American National Committee of the International Geodetic and Geophysical Union, and its executive committee is the Committee on Geophysics of the National Research Council. The American Geophysical Union is divided into several sections, following the plan of organization of the International Union. At the annual meeting in May 1930 a Section of Hydrology was authorized to conform to the Section of Scientific Hydrology of the International Union.

The chairman of the new section was Oscar Edward Meinzer (1876-1948), groundwater specialist of the U. S. Geological Survey and author of the article; Robert Horton and Herbert Eaton, whose names have already been mentioned, were vice chairman and secretary. Among the new committee chairmen of the section, Lorenz Straub was given responsibility for organizing research on rivers, and he stimulated a great deal of activity among Freeman Scholars and others interested in the subject. Beginning with the 1932 issue, the *Transactions* volumes were devoted in great measure to hydrology; this included many forms of hydraulics, especially the transportation of sediment, and played a considerable role in the dissemination of research results for the next decade.

In closing this chapter, detailed mention should be made of the several reviews of American laboratory development and productivity that exist in the literature. The report issued in 1922 by the Engineering Foundation was evidently what led, in the course of the Freeman hearings, to the frequent statement that America already had some 50 laboratories. In 1932 Morrough O'Brien's department of mechanical engineering at Berkeley proposed a continuing series of such reports and prepared a trial number. Shortly thereafter a circular letter was sent out by the American Committee of the World Power Conference, which prompted the new laboratory at the Bureau of Standards in 1933 to take over the California venture, including even its format. Two series of reports were initiated: (A) "Current Hydraulic Laboratory Research in the United States," and (b) "Hydraulic Laboratories in the United States." The latter initially described 63 laboratories, 75% of which were connected with universities and the remainder with governmental agencies and private companies; only two issues of this series appeared, the second being the slightly amplified version of 1935. However, in 1937 a more detailed survey of the principal American laboratories was published in the BSCE *Journal* by Leslie James Hooper (1903-. . . . .), a protégé of "Prof" Allen at Worcester, who spent his year as a Freeman Scholar touring the United States and Canada instead of Europe.

(Hooper eventually succeeded Allen in the directorship of the Alden Laboratory.)

The first issue of the Bureau's Series A contained brief descriptions of the projects under way in only 11 institutions, but by the second issue the number had increased to 30, and 500 copies were distributed. Originally planned as a quarterly, the report soon appeared only semiannually, then annually, and finally biennially for a total of more than forty years. Abstracts of completed studies were added to the running descriptions at an early date, followed in turn by lists of available translations, foreign laboratories, and publications in other languages. Paging through the successive issues of these reports reveals a very great deal of activity, though it is significant that by far the major part occurred in a relatively small fraction of the laboratories described. Much of what was detailed was purely for instructional purposes and much for specific projects that were hardly of a research nature. Only seldom did nuggets appear that were worth continued attention. Despite the considerable amount of repetitive work, however, one must not decry the low efficiency of the research effort, particularly since the investment was largely a matter of unsupported time. Surely much more was accomplished than would have been the case if only those who produced the nuggets had been active.

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PROCEEDINGS

BOSTON SOCIETY OF CIVIL ENGINEERS SECTION

AMERICAN SOCIETY OF CIVIL ENGINEERS

Meetings Held — Technical Groups

Environmental Group

June 23, 1976. Annual outing. Dinner at Valle's, Andover, Mass.; meeting at Andover Water Filtration Plant. Chairman Taurasi presided. Speaker, Robert E. McQuade, Director of Public Works, Andover. Subject "The Andover Marriage" — the town's filtration plant. Attendance, 21.

Geotechnical Group

June 3, 1976. Dinner at Roscoe Building, Harvard; meeting at Pierce Hall, Harvard. Speaker, Dr. Edward J. Cording, Professor of Civil Engineering, University of Illinois. Subject "The Design of Underground Openings in Rock."

Officers of the Group for 1976-1977 were elected as follows: Chairman, William S. Zoino; Vice Chairman, Peter K. Taylor; Clerk, David E. Thompson; Executive Committee, Alton P. Davis, Joseph D. Guertin, and Anthony Barila. Asaf Quazilbash was appointed Chairman of the Geotechnical Forum (sub-group.) Attendance, 45.

Transportation Group

May 20, 1976. Dinner meeting at Polcari's Restaurant. Russell Barnes presided in absence of Chairman Miller. Speakers, Robert J. McDonagh, Deputy Chief Engineer, Highway, for Mass. DPW and Kay K. Krekorian, Deputy Chief Engineer, Traffic Operations, Mass. DPW. Subject, "Reconstructing the Southeast Expressway." Attendance, 106.

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